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# Glycemic outcomes among rural patients in the type 1 diabetes T1D Exchange registry, January 2016–March 2018: a cross-sectional cohort study

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## ABSTRACT

**Introduction** Does rural status influence glycemic outcomes among participants in the type 1 diabetes T1D Exchange clinic registry?
**Research design and methods** Data from the T1D Exchange clinic registry between January 2016 and March 2018 were identified by rural–urban status and stratified by age and hemoglobin A1c (HbA1c). Multivariable regression modeling was performed to isolate HbA1c differences. A full model including all significant (p<0.05 via two-sided testing) differential factors was determined with an additional indicator for rural status, and adjusted for duration of diabetes, use of continuous glucose monitoring device, age, race/ethnicity, and private insurance status. The model was reduced using backwards elimination stepwise procedures until only significant factors remained.
**Results** Mean HbA1c levels for all rural participants were significantly higher (8.71%; 72 mmol/mol) compared with the urban group (8.48%; 69 mmol/mol), p<0.001. For youth under 13 years of age, rural participants had a higher mean HbA1c (8.65%; 71 mmol/mol) compared with urban (8.45% 69 mmol/mol), p=0.022. Rural youth (13–<18 years) had a higher mean HbA1c (9.39%; 79 mmol/mol) than urban youth (9.14%; 76 mmol/mol), p<0.001. Rural young adults (18–<26 years) had a higher mean HbA1c (9.07%; 76 mmol/mol) than urban young adults (8.88%; 74 mmol/mol), p=0.042. Rural adults (≥26 years; n=589) were the only group that did not have a higher mean HbA1c (7.76%, 61.3 mmol) than urban adults (n=4770; 7.72%, 60.9 mmol/mol), p=0.503. Rural locale was highly significant (beta=0.175, p<0.001) despite controlling for potentially confounding differences between rural and urban groups.
**Conclusions** Among this T1D Exchange cohort, there is a pattern of higher mean HbA1c being associated with rural status, even after adjustment for characteristic differences, most strikingly among those under 26 years of age. This disparity and contributing factors need to be more thoroughly studied to provide effective solutions.

## Significance of this study

### What is already known about this subject?

- Diabetes prevalence and mortality are higher among rural Americans.
- Limited information is known about type 1 diabetes among rural Americans.

### What are the new findings?

- Despite data for this study being collected via endocrinology services, this analysis of the type 1 diabetes T1D Exchange registry found that rural participants had worse glycemic control than participants from urban areas.
- Rural youth under age 26 years had worse mean hemoglobin A1c (HbA1c) values than urban youth of the same age.
- For adults aged 26 years and over, there were no differences in HbA1c between rural and urban groups.

### How might these results change the focus of research or clinical practice?

- Rural residence and associated barriers encountered among rural-residing persons with type 1 diabetes should be anticipated and addressed in care planning.
- Researchers and providers working in rural areas should strive to provide creative care delivery solutions that can reach patients and their families where they reside.

## INTRODUCTION

One in five Americans (about 60 million people) live in a rural area,[1] and they also carry a higher burden of chronic disease compared with their urban counterparts.[2] Incidence of type 1 diabetes among rural Americans has been reported to be 2.28 times (95% CI 2.08 to 2.50) that of persons living in high-density areas,[3] and it is well recognized that prevalence of type 1 diabetes in the USA and worldwide is increasing.[4] While there have been positive changes in diabetes-related mortality over time, urban mortality rates have decreased almost three to five times more than the rates observed in rural areas.[5]

Multiple barriers, including those related to socioeconomic and transportation issues, contribute to rural diabetes disparities.

Additionally, there is often a culture of self-reliance and hesitancy to use urban-based medical resources.[2 6] Limited access to endocrinology specialty care in rural communities is another barrier to rural diabetes outcome improvement.[7 8] These significant and ongoing diabetes health disparities throughout rural America[5 9 10] have instigated discussions about how rural health equity can be improved.[11] Moreover, type 1 diabetes outcomes have not been thoroughly studied in the context of rural residence.

The type 1 diabetes T1D Exchange clinic registry was established in 2010 with more than 35 000 adult and youth participants of all ages. While not a nationally representative sample of persons with type 1 diabetes, the registry includes patients from 81 pediatric and adult endocrinology clinics from more than 35 states.[12] Beck *et al*[13] have published a complete description of the T1D Exchange clinic registry including participant recruitment, inclusion and exclusion criteria, and overall baseline characteristics. Analyses of the registry have covered topics varying from device use to disparities in treatments and outcomes.[12 14] To our knowledge, however, there has been no prior investigation of the T1D Exchange clinic registry comparing rural–urban participant glycemic observations. Additionally, there is limited understanding of the effects of rural status on type 1 diabetes outcomes.[15–18]

The purpose of this study was to investigate the cross-sectional mean hemoglobin A1c (HbA1c) and other diabetes-related characteristics among the rural and urban participants in the T1D Exchange. We hypothesized that disparities in glycemia, as indicated by mean HbA1c, would diminish significantly because all T1D Exchange registry participants receive diabetes care via endocrinology services. We also believed it would be of interest to look at the T1D Exchange clinic registry data through the lens of rural residence stratified by age-specific groupings (all ages; youth below 13 years; youth 13–<18 years; young adults 18–<26 years; and adults 26 years of age and older), and predetermined HbA1c ranges (<7% (<53 mmol/mol), 7%–<9% (53–<75 mmol/mol), and ≥9% (≥75 mmol/mol)).

## RESEARCH DESIGN AND METHODS

Study data for this retrospective cohort analysis were obtained from the T1D Exchange registry of participants between January 1, 2016 and March 31, 2018. Year 5 data were provided with registrant zip codes by the Jaeb Center for Health Research T1D Exchange clinic registry team.[12 19] Year 5 data include registrants who were followed for 5 years and completed the baseline and year 5 questionnaires.

Variables for this study were obtained through medical records and patient questionnaires completed by patients and/or their guardians, which is explained more thoroughly by Foster *et al*.[12] Age, duration of diabetes, body mass index, insulin pump and continuous glucose monitoring (CGM) device use, non-insulin glucose-lowering medication use, and HbA1c levels were collected via medical records. Self-monitoring of blood glucose habits were reported as meter downloads when available, or self-report. Occurrences of severe hypoglycemia (SH; defined as loss of consciousness or seizure) and diabetic ketoacidosis (DKA; defined as requiring overnight hospitalization) were reported if they occurred in the 3 months before the participant/caregiver completed the year 5 questionnaire.[12] The analysis for participant diabetes control is based on the calculated average prior 12 months' HbA1c from the year 5 questionnaire.

Data were imported into SPSS V.25.0 software and the cohort was stratified by rural location status (Yes/No) based on zip code as determined by the Centers for Medicaid and Medicare Services (CMS)[20] definitions of rurality for payment, which defines 'rural' by zip code based on urbanized areas and clusters.[21] We recognize there are many ways to define rural,[22] but we chose to use the CMS rurality for payment definition as it was feasible and efficient for our small research team's limited resources, and it is also based on a real-world and clinically meaningful application (eg, payment for medical care/equipment). For simplicity, we will use the terms 'rural' and 'urban' to describe the two groups reported here.

The age group cut-offs and HbA1c categories used to frame our analysis were based on commonly used ranges from the literature[23 24] and adjusted to reflect the Affordable Care Act coverage available to those up to age 26 years. For age ranges, we used all ages; youth below 13 years; youth 13–<18 years; young adults 18–<26 years; and adults 26 years of age and older. For the predetermined HbA1c ranges, we used <7% (<53 mmol/mol), 7%–8.99% (53–<75 mmol/mol), and ≥9% (≥75 mmol/mol)). Looking specifically at mean HbA1c groupings across several age strata would allow us to more effectively investigate the youth-specific concerns, which is widely recognized as a difficult time period for optimal diabetes control,[12 25] and understudied in rural youth.

### Statistical analysis

Demographic data were summarized both overall for the entire cohort and by rural–urban status. Numeric data were summarized using means, SDs, and minimum to maximum range values. Comparisons between rural and urban groups for mean equality were performed via independent sample t-tests. Categorical data were summarized overall and by rural–urban status using frequencies and percentages. Depending on the cell sample sizes and ordinality of the data, either Pearson $X^2$ tests, Fisher's exact tests, linear association $X^2$ tests, or exact linear association tests were performed to compare rural with urban location status for distributional equality.

**Table 1** Demographic characteristics

| | Urban, n (%) | Rural, n (%) | P value |
|---|---|---|---|
| Total participants, n (%) | 12 476 (100) | 1837 (100) | 0.040 |
| Age in years, mean (SD) | 28.9 (18.06) | 27.9 (19.33) | 0.040 |
| Child (<13 years) | 1188 (9.5) | 224 (12.2) | <0.001 |
| Adolescent (13–<18 years) | 3567 (28.6) | 609 (33.2) | |
| Young adult (18–<26 years) | 2951 (23.7) | 415 (22.6) | |
| Adult (26+ years) | 4770 (38.2) | 589 (32.1) | |
| Gender, n (%) | | | 0.316 |
| Female | 6375 (51.1) | 964 (52.5) | |
| Male | 6097 (48.9) | 872 (47.5) | |
| Transgender | 4 (0.0) | 1 (0.1) | |
| Race/ethnicity, n (%) | | | <0.001 |
| White non-Hispanic | 10 399 (83.4) | 1697 (92.4) | |
| Black non-Hispanic | 565 (4.5) | 25 (1.4) | |
| Hispanic or Latino | 982 (7.9) | 60 (3.3) | |
| Other | 530 (4.2) | 55 (3.0) | |
| Annual income, n (%) | | | <0.001 |
| Missing/unreported | 5881 (47.1) | 883 (48.1) | |
| <\$50 000 | 1726 (26.2) | 338 (35.4) | |
| \$50 000–\$75 000 | 934 (14.2) | 203 (21.3) | |
| >\$75 000 | 3935 (59.7) | 413 (43.3) | |
| Education, n (%) | | | <0.001 |
| Missing/unreported | 3493 (28.0) | 557 (30.3) | |
| Less than HS diploma | 2362 (26.3) | 416 (32.5) | |
| HS diploma/GED | 2500 (27.8) | 402 (31.4) | |
| Associate's degree | 565 (6.3) | 118 (9.2) | |
| Bachelor's degree | 2047 (22.8) | 226 (17.7) | |
| Master's degree | 1092 (12.2) | 94 (7.3) | |
| Professional/doctoral degree | 417 (4.6) | 24 (1.9) | |
| Insurance status, n (%) | | | <0.001 |
| Private | 9477 (77.1) | 1240 (69.2) | |
| Other | 2728 (22.2) | 533 (29.7) | |

GED, General Educational Diploma; HS, high school.

Treatment-related and crude outcome data were similarly summarized and analyzed. Due to characteristic differences between the rural and urban strata for demographic and/or treatment-related data, a multivariable linear regression model was employed to adjust for these differences. A full multivariable regression model including all significant (p<0.05 via two-sided testing) differential factors (duration of diabetes, age, use of CGM, race/ethnicity, and private insurance status) was determined, with an additional indicator factor for rural status. Two factors, education and income, were significant but not included in the model due to missing data ranging from 28% to over 48% of the rural and urban sample, which could have biased the model. Therefore, we used insurance status as a proxy measure for socioeconomic status, rather than education and income. Finally, the multivariable model was reduced using backwards elimination stepwise procedures until only significant (p<0.05 via two-sided testing) factors were included.

For the primary outcome variables, mean HbA1c and number of HbA1c measurements, the percentage of non-missing, subject-level data were determined to be above 98% for each strata. Similarly for the multivariable regression model, the percentage of complete subject data including non-missing data for all predictive factors was determined to be 93.9%. Due to the completeness of the data, missing data were not included in the analyses and no imputation was performed. All data are based on the 12-month time frame within the data collection

Table 2 Diabetes-related health characteristics

| | Urban, n (%) | Rural, n (%) | P value |
|---|---|---|---|
| Age at diagnosis (years), n (%) | 12476 (100) | 1837 (100) | 0.663 |
| Mean (SD) | 11.6 (11.19) | 11.5 (11.70) | |
| Duration of diabetes (years), n (%) | 12475 (>99.9) | 1837 (100) | 0.004 |
| Mean (SD) | 17.3 (12.40) | 16.4 (12.60) | |
| Use of CGM, n (%) | 3684 (30.5) | 420 (23.6) | <0.001 |
| Use of insulin pump, n (%) | 8056 (65.7) | 1224 (67.4) | 0.142 |
| BMI ($m^2$/kg), n (%) | 11316 (90.7) | 1705 (92.8) | 0.731 |
| Mean (SD) | 25.4 (5.70) | 25.4 (5.71) | |
| Total daily insulin (units per kg), n (%) | 7270 (58.3) | 1151 (62.7) | 0.089 |
| Mean (SD) | 0.78 (0.30) | 0.79 (0.30) | |
| Use of non-insulin medications for blood sugar control, n (%) | | | 0.874 |
| Missing/unreported | 2619 (21.0) | 361 (19.7) | |
| Yes | 836 (8.5) | 127 (8.6) | |
| No | 9021 (91.5) | 1349 (91.4) | |
| General health (patient reported), n (%) | | | 0.644 |
| Missing/unreported | 3262 (26.1) | 525 (28.6) | |
| Excellent | 1602 (17.4) | 227 (17.3) | |
| Very good | 3523 (38.2) | 487 (37.1) | |
| Good | 2945 (32.0) | 443 (33.8) | |
| Fair | 976 (10.6) | 136 (10.4) | |
| Poor | 168 (1.8) | 19 (1.4) | |
| Smoke at least 1 cigarette/week, n (%) | | | 0.127 |
| Missing/did not wish to answer | 5055 (40.5) | 822 (44.7) | |
| Yes | 304 (4.1) | 52 (5.1) | |
| No | 7117 (95.9) | 963 (94.9) | |
| Days per week exercising, n (%)* | 8493 (68.0) | 1184 (64.5) | 0.383 |
| Mean (SD) | 4.0 (2.11) | 4.0 (2.19) | |
| ≥1 DKA events in past 3 months, n (%) | | | 0.517 |
| Missing | 3262 (26.1) | 525 (28.6) | |
| Yes | 252 (2.7) | 40 (3.0) | |
| No | 8962 (97.3) | 1272 (97.0) | |
| ≥1 severe hypoglycemic events† in past 3 months, n (%) | | | 0.937 |
| Missing | 3262 (26.1) | 525 (28.6) | |
| Yes | 567 (6.2) | 80 (6.1) | |
| No | 8647 (93.8) | 1232 (93.9) | |
| Average patient-reported SMBG/day, n (%) | 9055 (72.6) | 1287 (70.1) | 0.629 |
| Mean (SD) | 4.88 (2.42) | 4.91 (2.33) | |
| Average glucose tests/day from meter download, n (%) | 8635 (69.2) | 1382 (75.2) | 0.619 |
| Mean (SD) | 4.19 (2.47) | 4.23 (2.49) | |

*Exercise was only reported for youth and young adults below age 26 years.
†Severe hypoglycemic events were defined as an episode of documented or presumed low blood glucose that resulted in seizure or loss of consciousness per Cengiz *et al*.[39]
BMI, body mass index; CGM, continuous glucose monitoring; DKA, diabetic ketoacidosis; SMBG, self-monitoring of blood glucose.

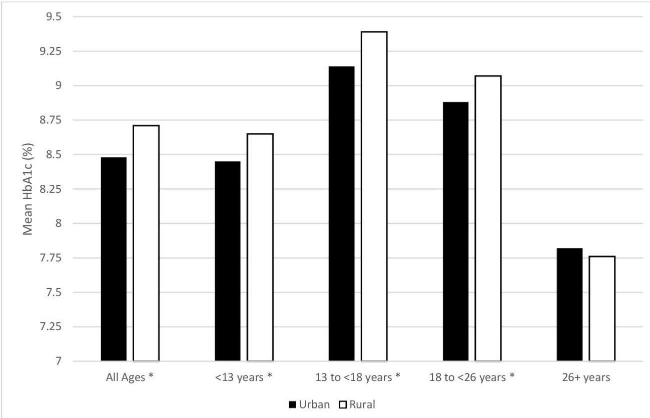


**Figure 1** Mean HbA1c by age group and rural status. *Significant difference between urban and rural participants. All ages: p<0.001; below 13 years of age: p=0.022; 13–below 18 years of age: p=0.001; 18–26 years of age: p=0.042; 26 years of age and older: p=0.503. HbA1c, hemoglobin A1c.

period (January 2016–March 2018) when participants or caregivers completed their year 5 questionnaire.

## RESULTS

### Demographics

A total of 14 313 registrants were included in this analysis (1837 rural, 13%; and 12 476 urban, 87%). The rural and urban participants in this analysis differed significantly across multiple demographic variables, summarized in table 1. Briefly, rural participants differed significantly from the urban group by age distribution (p=0.04), but both groups were primarily non-Hispanic white (rural, 92.4%; urban, 83.4%). Overall, rural participants reported lower income and educational attainment than urban participants (p<0.001). Both groups reported having primarily private insurance, but more urban participants had private insurance compared with those in the rural group (n=9477, 77.1%; and n=1240, 69.2%, respectively, p<0.001).

### Diabetes-related health characteristics

The two groups varied in some, but not all, diabetes-related health characteristics (table 2). Age at diagnosis for type 1 diabetes onset was not different between the urban and rural groups (11.6 years, 11.19 SD; and 11.5 years, 11.70 SD, respectively), however, the urban group had a significantly longer duration of diabetes (17.3 years, 12.4 SD) than the rural group (16.4 years, 12.60 SD; p=0.004).

Diabetes device use was also different between the groups. Use of CGM was significantly higher among participants in the urban compared with rural groups (n=3684, 30.5%; n=420, 23.6%, respectively; p<0.001), but insulin pump use was not significantly different (n=8056, 65.7% for the urban group; n=1224, 67.4% for the rural group; p=0.142).

No other significant differences were found in other diabetes-related health characteristics including body mass index, total daily dose of insulin per kilogram body weight (rural group mean 0.79 units/kg, SD 0.30; urban group mean 0.78 units/kg, 0.30 SD, p=0.089), use of non-insulin medications, general self-rated health, smoking status, or reported days per week of exercise. There were also no differences in reported instances of DKA (urban mean affirming DKA episode n=252, 2.7%; rural mean n=40, 3.0%; p=0.517), or severe hypoglycemic (SH) episodes (urban mean affirming SH episodes n=567, 6.2%; rural mean n=80, 6.1%; p=0.937). There were also no differences in the frequency of self-reported monitoring of blood glucose (mean tests per day for rural 4.91, SD 2.33; urban 4.88, SD 2.42; p=0.629), or the average number of tests downloaded from glucometers (rural 4.23, SD 2.49; urban 4.19, SD 2.47; p=0.619).

### HbA1c: number of measurements and mean values

Across all age strata, there were significantly more HbA1c measurements taken within the past year of the data collection period among the rural versus urban group (3.18 mean tests, 1.25 SD; 3.08 mean tests, 1.37 SD, respectively, p=0.003). Rural adults over the age of 26 years had significantly more HbA1c tests (2.90 tests in the past 12 months, 1.19 SD) compared with those in the urban group (2.67 tests in the past 12 months, 1.31 SD; p<0.001).

Figure 1 and table 3 present the mean HbA1c findings across all age strata by rural–urban status. Briefly, rural participants had significantly higher mean HbA1c (8.71% or 72 mmol/mol, 1.66 SD; p<0.001) compared with urban participants (8.48%, 69 mmol/mol; 1.63 SD). Fewer rural youth 13–<18 years of age had an HbA1c between 7% (53 mmol/mol) and 8.99% (75 mmol/mol) compared with urban youth (n=273; 45.1% and n=1772; 50.1%, respectively, p=0.002). More rural youth between 13 and <18 years of age had an average HbA1c 9% (75 mmol/mol) and over compared with the urban group (n=315; 52.1% and n=1596; 45.1%, respectively, p<0.002).

### Multivariable linear regression

After adjustment for characteristic differences (duration of diabetes, use of CGM, age, race/ethnicity, and private insurance), rural location was a statistically significant factor in the reduced model for predicting average HbA1c value (beta=0.175, p<0.001) (table 4). Rural locale was associated with a significantly increased HbA1c even after identifying and adjusting for significant characteristic differences in potentially confounding factors between the rural and urban strata.

## DISCUSSION

After examination of all age groups, this analysis of the 2016–2018 T1D Exchange registry cohort found that rural participants under 26 years of age had significantly higher average HbA1c values than urban participants. Moreover, when looking at the T1D Exchange sample stratified by both age and HbA1c, we continued to find that the HbA1c generally worsens among the younger

Table 3 HbA1c outcomes by age and rural status

| | HbA1c | Urban, n (%) | Rural, n (%) | P value |
|---|---|---|---|---|
| All ages | <7% | 1725 (14.1) | 179 (9.9) | <0.001 |
| | 7%–8.99% | 6833 (55.8) | 1002 (55.3) | |
| | ≥9% | 3689 (30.1) | 631 (34.8) | |
| | Average | | | <0.001 |
| | n (%) | 12 247 (98.2) | 1812 (98.6) | |
| | Mean (SD) | 8.48 (1.63) | 8.71 (1.66) | |
| <13 years | <7% | 81 (6.9) | 6 (2.7) | 0.059 |
| | 7%–8.99% | 771 (65.7) | 151 (68.0) | |
| | ≥9% | 322 (27.4) | 65 (29.3) | |
| | Average | | | 0.022 |
| | n (%) | 1174 (98.8) | 222 (99.1) | |
| | Mean (SD) | 8.45 (1.19) | 8.65 (1.17) | |
| 13–<18 years | <7% | 170 (4.8) | 17 (2.8) | 0.002 |
| | 7%–8.99% | 1772 (50.1) | 273 (45.1) | |
| | ≥9% | 1596 (45.1) | 315 (52.1) | |
| | Average | | | 0.001 |
| | n (%) | 3538 (99.2) | 60 (99.3) | |
| | Mean (SD) | 9.14 (1.69) | 9.39 (1.73) | |
| 18–<26 years | <7% | 269 (9.2) | 30 (7.3) | 0.115 |
| | 7%–8.99% | 1506 (51.7) | 200 (48.7) | |
| | ≥9% | 1140 (39.1) | 181 (44.0) | |
| | Average | | | 0.042 |
| | n (%) | 2915 (98.8) | 411 (99.0) | |
| | Mean (SD) | 8.88 (1.78) | 9.07 (1.77) | |
| ≥26 years | <7% | 1205 (26.1) | 126 (22.0) | 0.033 |
| | 7%–8.99% | 2784 (60.3) | 378 (65.9) | |
| | ≥9% | 631 (13.7) | 70 (12.2) | |
| | Average | | | 0.503 |
| | n (%) | 4620 (96.9) | 574 (97.5) | |
| | Mean (SD) | 7.72 (1.21) | 7.76 (1.15) | |

HbA1c, hemoglobin A1c.

population and improves with age, illustrated by rural youth having worse mean HbA1c levels than their urban counterparts. Similarly, but not significantly different due to the small convenience sample size, Stumetz *et al*[26] also reported higher HbA1c levels among their sample of 61 youth with type 1 diabetes (mean age 13.3 years) for rural (9%; 75 mmol/mol) versus urban (8.5%; 69 mmol/mol) participants.

Frequency of HbA1c monitoring, which can contribute to overall glycemic control, was higher in the rural cohort reported herein. The American Diabetes Association Standards of Medical Care in Diabetes recommends testing HbA1c levels more often among those adults with HbA1c above 7%.[27] The importance of frequent HbA1c monitoring among those with type 1 diabetes was established with the Diabetes Control and Complications Trial[28] and others.[29] More recently, a study with over 15 000 Austrian and German patients with type 1 diabetes found both mean HbA1c (different between rural and urban in our study) and self-monitoring of blood glucose (not different between rural and urban in our study) were associated with achieving target HbA1c.[30] Specifically, among the rural adults aged 26 years and over in our study, we found an increased average number of HbA1c tests reported, which could contribute to the improved HbA1c in adults—both rural and urban. Previous research has found that while rural physicians do indeed order HbA1c tests, many rural patients do not have optimal control of their diabetes,[31 32] which aligns with our findings.

The significantly higher usage of CGM among urban participants is likely related to the differences in

Table 4 Multivariable regression model for factors influencing HbA1c outcomes

| Outcome/factors | Factor effect—full model Beta (SE) | 95% CI | P value | Factor effect—reduced model Beta (SE) | 95% CI | P value |
|---|---|---|---|---|---|---|
| Mean HbA1c in past 12 months n=13 436 (93.9%) | | | | | | |
| Intercept | 10.112 (0.068) | 9.979 to 10.245 | <0.001 | 10.149 (0.044) | 10.062 to 10.237 | <0.001 |
| Duration of diabetes | −0.006 (0.002) | −0.010 to −0.003 | <0.001 | −0.006 (0.002) | −0.010 to −0.003 | <0.001 |
| Use of CGM | −0.574 (0.028) | −0.630 to −0.519 | <0.001 | −0.574 (0.028) | −0.630 to −0.519 | <0.001 |
| Age | −0.024 (0.001) | −0.026 to −0.022 | <0.001 | −0.024 (0.001) | −0.027 to −0.022 | <0.001 |
| Race—white | −0.323 (0.064) | −0.449 to −0.198 | <0.001 | −0.359 (0.041) | −0.439 to −0.278 | <0.001 |
| Race—black | 0.723 (0.089) | 0.549 to 0.896 | <0.001 | 0.686 (0.073) | 0.543 to 0.830 | <0.001 |
| Race—Hispanic | 0.057 (0.078) | −0.096 to 0.209 | 0.464 | | | |
| Private insurance | −0.535 (0.031) | −0.596 to −0.475 | <0.001 | −0.537 (0.031) | −0.597 to −0.476 | <0.001 |
| Rural location | 0.176 (0.038) | 0.101 to 0.251 | <0.001 | 0.175 (0.038) | 0.100 to 0.250 | <0.001 |

Model was reduced using stepwise backwards elimination procedure with p<0.05 required for reduced model inclusion.
CGM, continuous glucose monitoring; HbA1c, hemoglobin A1c.

income and insurance status observed in this cohort. Previous research supports the association between greater CGM use, and socioeconomic status, as we found in the urban group in this study.[33–35] For rural families who have youth with type 1 diabetes, there can also be barriers to quality of care such as appointment adherence and communication between patients and providers.[26]

Our multivariable model controlled for many of the confounding factors already well recognized to influence glycemia in persons with type 1 diabetes: duration of diabetes, CGM use, race/ethnicity, and private insurance. It is important to note that black race, CGM status, and private insurance had larger effects on HbA1c than rurality in the multivariable regression model; however, those factors are already widely acknowledged as important predictors of disparities in type 1 diabetes outcomes.[7 12 36] Therefore, we believe it is noteworthy that rural status persisted as a significant predictor for HbA1c among this group with type 1 diabetes obtaining care at endocrinology clinics. While rurality has previously been reported as a negative influence on HbA1c, most of this work has been done among the adult population with type 2 diabetes.[18 37]

As these data were collected and analyzed prior to the COVID-19 pandemic, there is no way to know the impact of the pandemic's widespread adoption of virtual medical visits and telemedicine on the T1D Exchange participant sample we reported on here, especially those living in rural communities. Technology-based approaches to increase and democratize[38] diabetes care access among socioeconomically and geographically at-risk rural communities can be effective. Researchers and clinicians should work towards building flexible solutions that meet a wide diversity of needs for rural patient populations with type 1 diabetes.

### Limitations

Despite our large, multistate sample, there are limitations. This sample does not include all persons with type 1 diabetes throughout the USA. The data are from those participants who obtained care at endocrinology clinics, consented to participate in the T1D Exchange registry, and therefore does not capture patients with type 1 diabetes who obtained healthcare from other providers (eg, internal medicine, pediatricians, or family practice providers), or patients who chose not to participate in the registry. The data on insurance coverage are very generalized (only reported as private, public, or other), so we were unable to determine more specific information concerning insurance coverage, underinsured, and uninsured status in this sample. Due to the lack of detail about participant education and income, the linear regression model could be biased. We chose to use the CMS methodology for defining rural, but there are many ways to define rural, so these findings should be interpreted with some caution.[22] We were not able to obtain psychosocial data (eg, depression, quality of life) for this cohort beyond general health status. Despite these limitations, we believe this study sheds light on an understudied group of rural Americans living with type 1 diabetes.

## CONCLUSIONS

In this analysis of a 2-year span of the T1D Exchange clinic registry participants, all receiving care at endocrinology clinics, we found significantly different levels of glycemic control among rural versus urban participants, especially in youth. The demographic differences reported here showed the rural group had lower levels of education, income, and less private insurance coverage. More importantly, our model showed that the disparities in glycemic control in this sample remained significantly associated with rural participant location even after controlling for other more significantly associated factors including duration of diabetes, CGM use, age, race/ethnicity, and private insurance status. To our knowledge, this is the first study to look specifically at rurality and HbA1c levels among a large sample of the American population with type 1 diabetes. With approximately 20% of Americans living in rural communities, there is still much more to be done to fully address the commonly recognized health disparities observed in rural America, and those living with type 1 diabetes.

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