Research Letter | Diabetes and Endocrinology

Association of Continuous Glucose Monitoring Use and Hemoglobin A₁c Levels Across the Lifespan Among Individuals With Type 1 Diabetes in the US

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Introduction

Type 1 diabetes (T1D) affects individuals of all ages, including a growing population of older adults.¹ Small, remote continuous glucose monitoring (CGM) devices²,³ are now recommended as the standard for glucose monitoring for T1D.² However, few studies have examined age, the probability of CGM use, and the association of CGM use with glycemic control across the lifespan.

Methods

This cross-sectional study used data from the national T1D Exchange Registry (2017-2018) for individuals aged 10 to 85 years. This registry includes data from patients with T1D at 80 US clinics nationwide,⁴ which are collected through medical record extraction and patient questionnaires. The University of North Carolina Institutional Review Board deemed this study exempt from review owing to the use of deidentified data. Informed consent was obtained from each participant (or by a parent or guardian if aged <18 years) by the original investigators. The study followed the STROBE reporting guideline.

We fit a generalized additive model⁵ estimating the probability of CGM use with age specified as a penalized spline, and we controlled for health insurance, sex, annual household income, race and ethnicity, education level, and insulin delivery method. We included race and ethnicity variables owing to well-documented disparities in diabetes treatments and outcomes among Black and Hispanic individuals. We present results as the fitted probability of CGM use across age. We then fit a linear regression model estimating hemoglobin A₁c (HbA₁c) levels by CGM use, age, age squared, and interaction of CGM use and age, controlling for the same covariates as described. We used the inverse probability of treatment weights and included the same covariates in both the propensity score and HbA₁c outcome models for a doubly robust approach. We imputed missing covariates for HbA₁c modeling using multivariate imputation via chained equations.

We used 2-sided hypothesis tests with a significance threshold of \( P < .05 \). Data were modeled using R version 4.1.0 (R Foundation for Statistical Computing) and Stata 16.1 (StataCorp).

Results

Our sample included 19,261 patients aged 10 to 85 years (mean [SD] of 27.58 [17.65] years) with T1D (Table). Of these individuals, 9,745 (50.59%) were female and 9,478 (49.21%) were male; sex was unknown for 38 (0.20%). The mean (SD) HbA₁c level was 8.57% (1.81%) (to convert to a proportion of total hemoglobin, multiply by 0.01), and 5,779 patients (30.00%) reported CGM use.

The adjusted probability of CGM use decreased in adolescence, increased afterward until approximately age 40, remained relatively constant until age 60, and then decreased until age 75 (Figure). CGM use was associated with lower HbA₁c levels across age compared with nonuse, but this association waned with increased age. The adjusted mean difference in HbA₁c levels among CGM users relative to nonusers was −0.70% at age 10 years (ie, 0.70% lower among users), which
decreased to −0.62% at 20, −0.55% at 30, −0.48% at 40, −0.41% at 50, −0.34% at 60, −0.27% at 70, −0.20% at 80, and −0.16 at 85 years.

**Discussion**

This cross-sectional study found that CGM use varied across age, with the highest adjusted probability occurring in middle adulthood. Furthermore, the probability of CGM utilization decreased with increasing age in older adulthood, reflecting the barriers that Medicare patients face regarding

| Characteristic                        | Patients* Overall (N = 19,261) | By CGM use Nonusers (n = 13,482) | Users (n = 5,779) |
|---------------------------------------|---------------------------------|----------------------------------|-------------------|
| Age, mean (SD), y                     | 27.58 (17.65)                  | 26.64 (17.36)                   | 29.77 (18.13)     |
| Hemoglobin A1c, mean (SD)b            | 8.57 (1.81)                    | 8.86 (1.89)                     | 7.90 (1.37)       |
| Sex                                   |                                 |                                 |                   |
| Female                                | 9745 (50.59)                   | 6723 (49.87)                    | 3022 (52.29)      |
| Male                                  | 9478 (49.21)                   | 6713 (49.94)                    | 2745 (47.50)      |
| Unknown                               | 38 (0.20)                      | 26 (0.19)                       | 12 (0.21)         |
| Race and ethnicityc                   |                                 |                                 |                   |
| American Indian or Alaska Native      | 84 (0.44)                      | 70 (0.52)                       | 14 (0.24)         |
| Asian                                 | 205 (1.06)                     | 140 (1.04)                      | 65 (1.12)         |
| Black non-Hispanic                    | 1045 (5.43)                    | 945 (7.01)                      | 100 (1.73)        |
| Hispanic or Latino                    | 1563 (8.11)                    | 1258 (9.33)                     | 305 (5.28)        |
| Native Hawaiian or other Pacific Islander | 27 (0.14)                 | 24 (0.18)                       | 3 (0.05)          |
| White non-Hispanic                    | 15,696 (81.49)                 | 10,555 (78.29)                  | 5141 (88.96)      |
| Multiple races or ethnicities         | 518 (2.69)                     | 401 (2.97)                      | 117 (2.02)        |
| Unknown                               | 123 (0.64)                     | 89 (0.66)                       | 34 (0.59)         |
| Health insurance                      |                                 |                                 |                   |
| Private                               | 13,813 (71.71)                 | 8936 (66.28)                    | 4877 (84.39)      |
| Public or single service              | 4458 (23.15)                   | 3778 (28.02)                    | 680 (11.77)       |
| Uninsured                             | 196 (1.02)                     | 167 (1.24)                      | 29 (0.50)         |
| Unknown                               | 794 (4.12)                     | 601 (4.46)                      | 193 (3.34)        |
| Annual household income, $            |                                 |                                 |                   |
| ≤35 000                               | 2608 (13.54)                   | 2210 (16.39)                    | 398 (6.89)        |
| 35 001-50 000                         | 1634 (8.48)                    | 1267 (9.40)                     | 367 (6.35)        |
| 50 001-75 000                         | 2378 (12.35)                   | 1677 (12.44)                    | 701 (12.13)       |
| ≥75 001                               | 7431 (38.58)                   | 4470 (33.16)                    | 2961 (51.24)      |
| Unknown                               | 5210 (27.05)                   | 3858 (28.62)                    | 1352 (23.40)      |
| Educational attainment                |                                 |                                 |                   |
| Less than high school                 | 930 (4.83)                     | 776 (5.76)                      | 154 (2.66)        |
| High school diploma                   | 2295 (11.92)                   | 1900 (14.09)                    | 395 (6.84)        |
| Some college but no degree            | 3458 (17.95)                   | 2709 (20.09)                    | 749 (12.96)       |
| Associate degree                      | 1961 (10.18)                   | 1442 (10.70)                    | 519 (8.98)        |
| Bachelor’s degree                     | 5159 (26.78)                   | 3230 (23.96)                    | 1929 (33.38)      |
| Graduate, doctorate, or professional degree | 3977 (20.65)         | 2280 (16.91)                    | 1697 (29.36)      |
| Unknown                               | 1481 (7.69)                    | 1145 (8.49)                     | 336 (5.81)        |
| Insulin modality                      |                                 |                                 |                   |
| Combination insulin pump and manual daily injections | 220 (1.14)                  | 145 (1.08)                      | 75 (1.30)         |
| Insulin pump                          | 11,976 (62.18)                 | 7217 (53.53)                    | 4759 (82.35)      |
| Manual daily injections               | 7026 (36.48)                   | 6089 (45.16)                    | 937 (16.21)       |
| Unknown                               | 39 (0.20)                      | 31 (0.23)                       | 8 (0.14)          |

Abbreviation: CGM, continuous glucose monitoring.

* Unless noted otherwise, data are presented as No. (% of patients). Percentages have been rounded and therefore may not total 100.

b To convert to a proportion of total hemoglobin, multiply by 0.01.

c The T1D Exchange Registry collects participant data through medical record extraction and questionnaires administered at care visits. Clinic staff contacted patients by phone to ascertain missing information. It is likely that some of the race and ethnicity data were obtained through self-report, whereas others may have been obtained through clinician notes in medical records.
CGM coverage. The clinically significant differences in HbA1c levels (>0.50%) among CGM users and nonusers among youth and adult populations underscore the need to identify age-related barriers to CGM use. Decreases in HbA1c differences over the lifespan suggest that adolescence is partly associated with higher HbA1c levels as well as possible survivorship bias, because older individuals with T1D may have better glycemic control regardless of CGM use. There are likely benefits to CGM use among older adults not reflected in the HbA1c outcome (eg, reduced hypoglycemia).

Limitations of this study include the cross-sectional design, which precludes causal inference. In addition, the predominance of non-Hispanic White individuals limits the generalizability of the findings to other racial and ethnic groups. Future work should explore patterns in CGM use and severe hypoglycemia, diabetic ketoacidosis, and health care utilization over the lifespan.
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