Change in Glycated Hemoglobin and Associated Factors in Diabetic Patients Using Flash Glucose Monitoring in a Colombian Institution: A Retrospective Cohort Study

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Abstract

Introduction: Diabetes mellitus (DM) is one of the leading causes of morbidity and mortality worldwide. Flash glucose monitoring (FGM) has been shown to improve metabolic control and reduce hypoglycemic events.

Objective: To analyze changes in glycated hemoglobin (HbA1c) and associated factors in adult patients with type 1 and 2 DM who initiated FGM use at a specialized IPS in Medellín, Colombia, between 2023 and 2024.

Materials and Methods: A retrospective, analytical cohort study with secondary data sources was included. 126 adult patients with DM who previously used capillary glucose monitoring and subsequently initiated FGM use were included. Baseline HbA1c values were compared with those obtained after ≥6 months of use. Descriptive analyses, the Wilcoxon test, bivariate analysis (chi-square, simple logistic regression), and multivariate analysis using Poisson regression with robust variance were applied.

Results: The median age was 41 years; 60% were women, and 67% had type 1 DM. HbA1c decreased significantly from 8.4% to 7.7% (median difference = 0.75; 95% CI: 0.55–0.94; $p < 0.001$). In the bivariate analysis, dyslipidemia and kidney disease were associated with a lower likelihood of HbA1c reduction, while health education was positively associated with changes in glycemic control. In the multivariate model, education (adjusted RR = 0.53; 95% CI: 0.27–0.93; $p = 0.041$) and kidney disease (adjusted RR = 0.63; 95% CI: 0.39–0.97; $p = 0.046$) remained significant factors.

Conclusions: Flash glucose monitoring significantly reduced HbA1c in patients with diabetes, with greater benefit in those who received health education. Kidney disease modified this association, requiring cautious interpretation of the results in this subgroup. Education and multidisciplinary support are consolidated as key factors for optimizing metabolic control.

Keywords: Diabetes mellitus; glycated hemoglobin; capillary glucometry; Flash Glucose Monitoring.

Introduction

According to the Pan American Health Organization (PAHO), noncommunicable chronic diseases (NCDs) are the leading cause of mortality and disability worldwide, accounting for 41 million deaths each year, representing 71% of global mortality. In the Americas, between 30% and 40% of individuals with diabetes remain undiagnosed, and between 50% and 70% of cases are uncontrolled, leading to preventable complications that generate high costs for the healthcare system (1).

Diabetes mellitus (DM) is a chronic metabolic disease characterized by elevated blood glucose levels which, over time, if not adequately controlled, result in macrovascular and microvascular damage to target organs (2). Acute complications include diabetic ketoacidosis and severe hypoglycemia, often requiring hospitalizations that could be prevented with adequate metabolic control and timely self-monitoring (3).

One of the diagnostic tests for detecting DM is the measurement of glycated hemoglobin (HbA1c), considered by the American Diabetes Association (ADA) as a diagnostic criterion in patients with suspected disease when its value is equal to or greater than 6.5%. Once diagnosed, patients should continuously monitor their glucose levels through capillary glucose monitoring (CGM), which involves obtaining a drop of blood from the fingertip using a glucometer (4).

The traditional self-monitoring method is capillary glucose testing; however, it may cause pain and psychological, biological, and social effects (5–10), which limit adherence and hinder insulin titration, ultimately contributing to poor metabolic control (5).

To address these limitations, new technologies for DM monitoring have been developed. Since 2014, flash glucose monitoring (FGM) has been introduced, allowing real-time measurement of interstitial glucose through a subcutaneous sensor and a portable reader (11). Several studies suggest that FGM, combined with individualized education, pharmacological treat-

ment, and lifestyle modifications, reduces HbA1c levels and the frequency of hypoglycemic events (4,11,12). In Colombia, evidence on the impact of FGM on HbA1c changes in real-world clinical practice remains limited, highlighting the need to generate local data to inform clinical and health management decision-making in the Colombian context.

Materials and Methods

Study Design, Type, and Population

A quantitative, observational, analytical, longitudinal, retrospective cohort study was conducted based on secondary data sources. Secondary sources were defined as clinical records previously collected for healthcare purposes rather than research. Information was obtained from electronic medical records and institutional databases. All adult patients diagnosed with type 1 and type 2 diabetes mellitus who were treated at a specialized healthcare institution (IPS) in Medellín, Colombia, were included; these patients initially used capillary glucose monitoring and subsequently initiated flash glucose monitoring (FGM).

Time zero was established between March 2023 and March 2024, and data collection concluded in November 2024. For each patient, a baseline HbA1c value prior to FGM initiation and a follow-up value ≥6 months after its use were recorded.

The dependent variable was the change in HbA1c (reduction ≥0.3% from baseline) (13), and independent variables included sociodemographic and clinical characteristics. The study design aimed not only to describe HbA1c variation but also to identify factors associated with these changes. As a census, all available records were included, and no sample size calculation was required.

No control cohort was included, as the study corresponded to an institutional census of patients who initiated FGM, without availability of a comparable non-intervention group during the same period. A before–after analysis allowed for intra-individual comparisons, reducing intersubject variability; additionally, multivariable adjustment by age and sex was performed to minimize residual confounding.

Data Collection

Data collection was conducted using the following sources: the educators' database, in which the pharmacy technician responsible for renewing FGM supplies recorded patients who initiated device use, and the Magna database managed by the nurse of the specialized care group within the institution.

With prior authorization from the institution's research committee, information was collected from the medical records of patients who initiated FGM use between March 2023 and March 2024, obtaining sociodemographic and clinical data. Subsequently, a database was constructed including the variables of interest in accordance with the study objectives.

Inclusion Criteria

Patients older than 18 years with a diagnosis of type 1 diabetes mellitus, type 2 diabetes mellitus, or latent autoimmune diabetes in adults (LADA) were included. Eligible participants had at least six months of capillary glucose monitoring and poor metabolic control (HbA1c ≥ 7%), initiated flash glucose monitoring (FGM) at the healthcare institution (IPS), and had no prior use of this technology. For patients with type 2 diabetes, only those on a basal–bolus insulin regimen were considered.

Exclusion Criteria

Patients with prior use of FGM or insulin pump therapy, pregnancy, corticosteroid treatment, discontinuation of FGM during follow-up, absence of HbA1c measurement ≥6 months after initiation, or other types of diabetes were excluded.

Handling of Missing Data

Missing data (<10%) were handled using simple imputation to preserve sample size: the median was imputed for quantitative variables and the mode for categorical variables. This approach allowed retention of the sample size without introducing substantial changes in variance or altering the overall distribution of the variables. Given the low proportion of missing data, more complex techniques, such as multiple imputation, were not deemed necessary.

Statistical Analysis

The analysis was performed using Jamovi 2.3. Descriptive statistics were calculated, including absolute and relative frequencies for qualitative variables, and measures of central tendency (mean ± standard deviation [SD] or median and interquartile range [IQR], depending on normality) for quantitative variables. Normality was assessed, and when assumptions were not met, the Wilcoxon signed-rank test for paired samples was used to compare HbA1c values before and after flash glucose monitoring (FGM), with a significance level set at $p < 0.05$.

To explore variables associated with changes in HbA1c, the outcome variable was dichotomized as "change" (reduction ≥0.3%) and "no change."

Bivariate analysis was conducted using the chi-square test for dichotomous categorical variables. For polytomous variables, simple binary logistic regression was used as an exploratory procedure to compare categories against a reference category. This phase was exploratory and aimed at variable selection.

In the bivariate analysis, although some independent variables had more than two categories (polytomous), the outcome remained strictly dichotomous (change vs. no change in HbA1c); therefore, simple binary logistic regression was employed as an exploratory approach to compare each category with a reference category.

A PROBIT model was not used, as it—like binary logistic regression—is designed for binary outcomes and yields equivalent estimates in terms of direction and statistical significance. The choice of the logistic model was based on its widespread use and ease of clinical interpretation through odds ratios, as well as its consistency with the subsequent implementation of the multivariable model based on relative risks.

Variables with $p < 0.25$ were selected for inclusion in the multivariable model, following the recommendation of Hosmer and Lemeshow, in order to avoid premature exclusion of potential confounders.

For multivariable analysis, considering that the event frequency was high (86%), traditional logistic regression was not appropriate for estimating relative risks, as the odds ratio may overestimate the magnitude of the effect when the outcome is common. Therefore, a multivariable Poisson regression model with robust variance was used, a recommended approach for estimating adjusted relative risks in cohort studies with frequent binary outcomes. This model allowed estimation of adjusted relative risks (RR) for the variables included in the model, with 95% confidence intervals, controlling for confounding by age and sex. The purpose of the model was explanatory rather than predictive.

Finally, since the main model was a Poisson regression with robust variance—a technique that does not directly allow estimation of variance inflation factors (VIF)—collinearity among independent variables was assessed using an auxiliary linear regression model among the predictors included in the multivariable model. VIF values ranged from 1.09 to 1.26, with tolerance values greater than 0.79, indicating no relevant collinearity among the independent variables. Therefore, no issues compromising the stability or interpretability of the final model estimates were identified.

Operationalization of Variables

Sociodemographic and clinical variables were analyzed as independent variables: age (<30, 30–49, ≥50 years), sex, marital status, educational level, residence in the metropolitan area of Medellín, time since diagnosis (<5/≥5 years), body mass index (BMI) (<25, 25–29.9, ≥30 kg/m^2), type of diabetes (type 1, type 2, LADA), comorbidities (hypertension, dyslipidemia, cancer, renal disease), use of glucagon-like peptide-1 (GLP-1) receptor agonists, history of hypoglycemia, and education on FGM (yes/no).

Baseline HbA1c and HbA1c at ≥6 months were continuous quantitative variables. The dependent variable was the change in HbA1c, defined as a reduction ≥0.3%. Follow-up time was categorized as 6 months–1 year and >1 year.

Bias and Confounding Control

As a retrospective cohort study based on secondary data, selection bias was minimized by including the institutional census and applying strictly defined criteria. Information bias was controlled through the use of electronic medical records and institutional databases with standardized records and verified FGM initiation dates. Temporal bias was avoided by ensuring that baseline HbA1c measurements preceded device initiation. Multivariable adjustment by age and sex was performed to control for potential confounding.

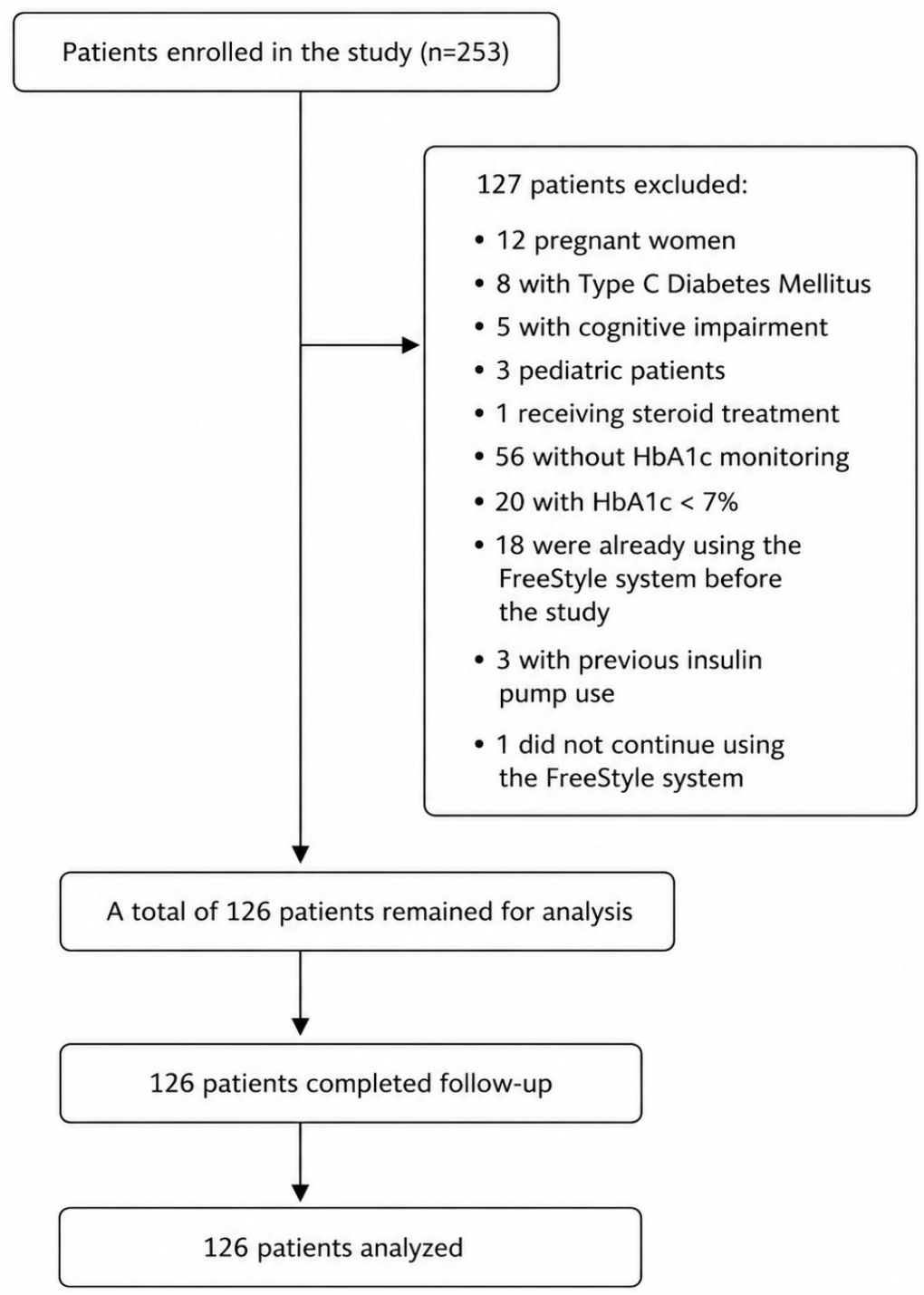
Ethical Considerations

Approval was obtained from the research committee of the healthcare institution under study for access to patient data. Additionally, this research was approved by the Research and Innovation Committee of the Faculty of Medicine at Universidad CES, according to Minutes No. 336 dated August 28, 2024. The principles established in the Declaration of Helsinki were followed, promoting the four fundamental ethical principles: respect for persons, beneficence, non-maleficence, and justice.

Results

Initially, 253 potentially eligible medical records were reviewed. After applying the inclusion and exclusion criteria, 127 clinical records were excluded. The final cohort consisted of 126 patient records, in which 19 variables of interest were analyzed to perform univariate, bivariate, and multivariable analyses (Figure 1).

Figure 1. Flowchart of inclusion and exclusion criteria



Descriptive Analysis of Sociodemographic Variables

It was found that 50% of the study population were 41 years old or younger; 6 out of 10 participants were female, more than 62% reported not having a partner, 9 out of 10 resided in the metropolitan area of the city, and more than half reported having a professional level of education (Table 1).

Table 1. Sociodemographic characteristics of the study population (N = 126)

Demographic Variables		N = 126	
		Absolute frequency	%
Age (years), median (*Q1-Q3) ***RIC**	41 (29 – 52,7) RIC 23.7		
Age	< 30 years	33	26,19
	≥30 years - < 50 years	55	43,65
	≥50 years	38	30,16
Gender	Female	76	60,32
	Male	50	39,68
Marital status	Married	33	26,19
	Separated	13	10,32
	Single	62	49,21
	Common-law union	15	11,90
	Widower	3	2,38
Within the Metropolitan area	Yes	108	85,71
	No	18	14,29
Professional	Yes	68	53,97
	No	58	46,03

*Q1: Quartile 1; **Q3: Quartile 3; ***IQR: Interquartile range.

Descriptive Analysis of Variables Related to Medical History

The body mass index (BMI) had a mean of 23.51 kg/m^2, with a standard deviation of 3.58, indicating that BMI values in this study population ranged between 19.93 and 27.09. This distribution is reflected in the categorical analysis, where 81% of participants had a BMI below 25, indicating that the majority of the study population had a normal weight.

Regarding the four comorbidities evaluated, dyslipidemia had the highest prevalence (54.76%, n = 69), followed by arterial hypertension (32.54%, n = 41). However, approximately 1 in 6 patients presented with some type of cancer. The least frequent comorbidities were renal disease (14.29%, n = 18) and cancer (6.35%, n = 8) (Table 2).

Table 2. Medical history of diabetic patients (N = 126)

Clinical Variables		N = 126	
		Absolute frequency	%
BMI*, kg/m2, mean (SD)**	23,51 (± 3,58)		
BMI, kg/m2.	< 25	81	64,29
	Between ≥25 - < 30	37	29,37
	≥ 30	8	6,35
Dyslipidemia	Yes	69	54,76
	No	57	45,24
High blood pressure	Yes	41	32,54
	No	85	67,46
Kidney Disease	Yes	18	14,29
	No	108	85,71
Cancer	Yes	8	6,35
	No	118	93,65

*BMI: Body Mass Index; **SD: Standard Deviation

Descriptive Analysis of Variables Related to Diagnosis and Management of Diabetic Patients

Prior to the descriptive analysis, raw data were explored using box plots and the Shapiro–Wilk normality test in Jamovi®, revealing a significant deviation from normality ($p < 0.00001$). Additionally, extreme values were identified in the continuous variables, which justified the use of the median and interquartile range as more appropriate measures of central tendency and dispersion.

The majority of patients had type 1 diabetes (65.8%, n = 83), compared to 14.2% (n = 18) with type 2 diabetes; 90.4% (n = 114) had more than five years since diagnosis. The median number of hypoglycemic events was 9 (IQR = 12), with 86.5% (n = 109) reporting at least one episode. Furthermore, 71.4% (n = 90) had a second HbA1c measurement between 6 and 12 months after initiating flash glucose monitoring. All patients attended at least one in-person educational session (median = 2; IQR = 2), and 91.3% (n = 115) received one or more sessions. HbA1c levels decreased from a median of 8.4% (IQR = 1.4) to 7.7% (IQR = 1.2) after device use, demonstrating a moderate and consistent reduction in glycemic control (Table 3).

Table 3. Characteristics of diagnosis and management of diabetic patients (N = 126)

Clinical variables		N= 126	
		Absolute frequency	%
Type of Diabetes Mellitus	LADA *	25	19,84
	Type 1	83	65,87
	Type 2	18	14,29
Type of Diabetes Mellitus	≤ 5 years	12	9,52
	> 5 years	114	90,48
Number of Hypoglycemia events during the use of Freestyle. Median (Q1-Q3) IQR	9 (3 – 15)		
Hypoglycemia during the use of Freestyle	Yes	109	86,51
	No	17	13,49
Use of GLP-1**	Yes	8	6,35
	No	118	93,65
Time of HbA1c* control post Freestyle insertion**	from 6 month to a 1 year	90	71,43
	Older than 1 year	36	28,57
Number of educational sessions post Freestyle insertion, Median (Q1-Q3) IQR	2 (1- 3)		
Education post Freestyle insertion	Yes	115	91,27
	No	11	8,73
Glycosylated hemoglobin before the use of Freestyle Median (Q1-Q3) IQR	8,4 (9,2 – 7,8)		
Glycosylated hemoglobin after the use of the Freestyle Median (Q1-Q3) IQR	7.7 (8.4 – 7.2) IQR 1.2		

* LADA: Latent Autoimmune Diabetes in Adults; **GLP-1: Glucagon-like Peptide-1 Agonists; ***HbA1C: Glycosylated Hemoglobin

Bivariate Analysis

Changes in glycated hemoglobin levels following the use of flash glucose monitoring (FGM) were assessed using the Wilcoxon signed-rank test for paired samples, as the continuous HbA1c variable (measured before and after in the same patients) did not follow a normal distribution according to the Shapiro–Wilk test ($p < 0.05$). Table 4 and Figure 2 present the differences in medians before and after the use of flash glucose monitoring in the same patients.

The difference in medians between these two measurements was 0.75 (95% CI: 0.55–0.94), with a p-value < 0.001, indicating a statistically significant difference between glycated hemoglobin medians at baseline and at ≥6 months after the use of flash glucose monitoring (Table 4) (Figure 2).

Table 4. Wilcoxon signed-rank test

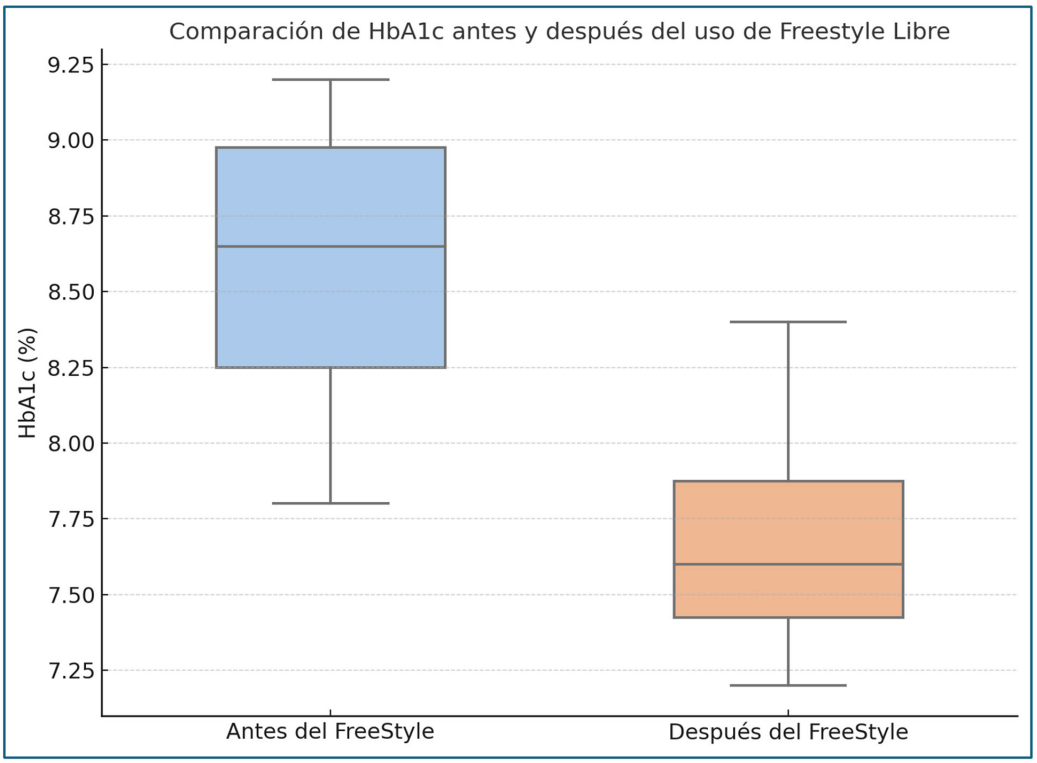
Characteristic	Pre-insertion Freestyle	Post-insertion of Freestyle	P Value
HbA1c Values, Median (IQR)	8,4 (7,8-9,2)	7,7 (7,2-8,4)	< 0,001

Characteristic	Median Difference HbA1c Pre and Post Insertion	**95% CI
HbA1c Values, Median	0,75	(0,55-0,94)

**CI: Confidence Interval

*HbA1c: Glycosylated Hemoglobin

Figure 2. Box plot



In Table 5, for the entire bivariate analysis, the "non-event" was defined as the absence of change in glycated hemoglobin, and the "event" as the presence of change, defined as a reduction ≥0.3%. Crude relative risks (RR) were estimated along with their corresponding 95% confidence intervals and p-values to identify statistically significant associations between the variables and the outcome.

During the bivariate analysis, patients under 30 years of age showed the highest proportion of change in glycated hemoglobin (73%), whereas among those older than 50 years, the proportion was lower (66%). Regarding sex, women exhibited a greater reduction (58%) and an RR of 1.22 compared to men; however, this association did not reach statistical significance. When analyzing marital status, separated patients showed the highest proportion of reduction (76.9%), although differences between categories were not statistically significant. Similarly, individuals with a professional level of education and residents of the metropolitan area of the city showed a higher frequency of change in HbA1c, although these findings were not statistically significant (Table 5).

Table 5. Bivariate analysis

Variables	No change in HbA1c N 40 (%)	With change in HbA1c N 86 (%)	RRc (95% CI)	P Value
Sociodemographic variables				
Age				
< 30 years	9 (27)	24 (73)	1,10 (0,80-1,53)	0,52
≥ 30 years - < 50 years	18 (33)	37 (67)	1,02 (0,76-1,40)	0,88
≥ 50 years	13 (34)	25 (66)	Ref.	-
Sex				
Female	26 (34,2)	50 (65,8)	Ref.	
Male	14 (28)	36 (72)	1,22 (0,70-2,1)	0,46
Marital status				
Single	18 (29,0)	44 (71,0)	Ref.	-
Married	14 (42,4)	19 (57,6)	1,80 (0,74-4,87)	0,19
Common-law union	4 (26,7)	11 (73,3)	0,88 (0,22-2,99)	0,85
Separated	3 (23,1)	10 (76,9)	0,73 (0,15-2,73)	0,66
Widowed	1 (33,3)	2 (66,7)	1,22 (0,05-13,4)	0,86
Professional				
Yes	19 (27,9)	49 (72,1)	Ref.	
No	21 (36,2)	37 (66,8)	0,77 (0,46-1,29)	0,32
Metropolitan Area				
Yes	33 (30,6)	75 (69,4)	Ref.	
No	7 (38,9)	11 (61,1)	0,78 (0,41-1,50)	0,48
Pathological history variables				
High blood pressure				
Yes	14 (34,2)	27 (65,8)	Ref.	0,68
No	26 (30,6)	59 (69,4)	1,12 (0,65-1,9)	

Dyslipidemia				
Yes	27 (39,13)	42 (60,87)	Ref.	0,05
No	13 (22,81)	44 (77,19)	1,71 (0,97-3,00)	
Cancer				
Yes	4 (50)	4 (50)	Ref.	0,26*
No	36 (30,5)	82 (69,5)	1,63 (0,77-3,45)	
Kidney disease				
Yes	10 (55,6)	8 (44,4)	Ref.	0,02
No	30 (27,8)	78 (72,2)	2,00 (1,19-3,34)	
Body Mass Index (BMI)				
<25	25 (30,9)	56 (69,1)	1,10 (-0,30-0,87)	0,72
>25 <30	12 (32,4)	25 (67,6)	1,08 (-0,38-0,86)	0,79
>30	3 (37,5)	5 (62,5)	Ref.	-
Clinical variables				
Hypoglycemias				
Yes	38 (34,8)	71 (65,2)	Ref.	0,090*
No	2 (11,8)	15 (88,2)	2,96 (0,78-11,2)	
GLP-1 Consumption				
Yes	1 (12,5)	7 (87,5)	Ref.	0,43*
No	39 (33,1)	79 (66,9)	0,37 (0,05 -2,41)	
HbA1c control time				
6 months to 1 year	31 (34,4)	59 (65,6)	Ref.	0,30
More than 1 year	9 (25)	27 (75)	1,38 (0,73-2,60)	
Education				
Yes	33 (28,7)	82 (71,3)	Ref.	0,035*
No	7 (63,6)	4 (36,4)	0,45 (0,26-0,76)	
Type of DM				
Type 1	28 (33,7)	55 (66,3)	Ref.	-
LADA Type	6 (24)	19 (76)	0,62 (-0,17-0,38)	0,31
Type 2	6 (33,3)	12 (66,7)	0,98 (-0,43-0,31)	0,97
Time of diagnosis				
< de 5 years	36 (31,6)	78 (68,4)	Ref.	1,00*
> de 5 years	4 (33,3)	8 (66,7)	1,06 (0,45-2,46)	

*Exact Fisher test

HbA1c: Glycosylated hemoglobin

RRc: Crude Relative Risk

GLP-1: Glucagon-like peptide agonists

Regarding comorbidities, non-hypertensive patients showed a greater reduction in HbA1c (69.4%), although this was not statistically significant. In contrast, dyslipidemia and renal disease were associated with a lower probability of HbA1c reduction; in both cases, these associations were statistically significant, with renal disease doubling the risk of not achieving improvement. Body mass index showed that patients with BMI <25 kg/m² had a greater reduction in HbA1c (69.1%), whereas overweight and obesity did not show significant differences (Table 5).

In terms of pharmacological treatment, the use of GLP-1 receptor agonists behaved as a protective factor, as 87.5% of patients receiving them showed a reduction in HbA1c; however, this finding did not reach statistical significance. Regarding the time between measurements, 75% of patients were followed up at one year or more, but this factor was not associated with changes in HbA1c. Health education, however, showed a relevant effect: 71.3% of patients who received at least one educational session experienced a reduction in HbA1c, and this finding was statistically significant (Table 5).

Finally, patients with LADA diabetes had the highest proportion of HbA1c reduction (76%), and those with less than five years since diagnosis achieved a reduction in 68.4% of cases. Nevertheless, in both scenarios, the differences were not statistically significant.

Multivariable Analysis

Variables with $p < 0.25$ in the bivariate analysis (renal disease, educational level, hypoglycemia, and dyslipidemia) were included, along with variables considered confounders according to the literature (age and sex), and those with biological plausibility (cancer and use of GLP-1 receptor agonists). In total, eight variables were incorporated with the aim of identifying which were associated with a higher or lower risk of presenting a change in glycated hemoglobin in this cohort of diabetic patients.

Renal disease and educational level were found to be statistically significantly associated with changes in glycated hemoglobin ($p < 0.05$). In the case of education, an underestimation of the effect was observed in the adjusted model compared to the crude relative risk, whereas for renal disease, an overestimation of the effect was observed after adjustment. The use of GLP-1 receptor agonists did not reach statistical significance, although the p-value was 0.058 (Table 6).

Table 6. Multivariable analysis

Variables	RRc (95% CI)	P Value	RRa (IC 95%)	P Value
Kidney disease	2 (1,19-3,34)	0,019	0,63 (0,39-0,97)	**0,046**
Sex	1,22 (0,70-2,1)	0,46	1,11 (0,85-1,45)	0,436
< 30 Yeras	0,72 (0,25-1,98)	0,52	0,93 (0,62-1,40)	0,751
≥30 years - < 50 years	0,93 (0,39-2,27)	0,88	0,97 (0,70-1,36)	0,882
≥ 50 years	Ref.		Ref.	
Education	0,45 (0,26-0,76)	0,03	0,53 (0,27-0,93)	**0,041**
Hypoglycemia	2,96 (0,78-1,2)	0,90	1,2 (0,90-1,78)	0,146
GLP-1	0,37 (0,05-2,41)	0,43	0,61 (0,37-1,03)	0,058
Dyslipidemia	1,71 (0,97-3,00)	0,50	0,8 (0,61-1,07)	0,142
Cancer	1,63 (0,77-3,45)	0,26	0,55 (0,27-1,03)	0,083

RRc: Crude Relative Risk

RRa: Adjusted Relative Risk

GLP-1: Glucagon-like peptide-1 receptor agonists

Given that the main model was a Poisson regression with robust variance, and this technique does not allow direct calculation of variance inflation factors (VIF), these were estimated using an auxiliary linear regression model that included the same independent variables as the multivariable model (age, sex, educational level, type of diabetes, renal disease, dyslipidemia, cancer, use of GLP-1, and hypoglycemia). Categorical variables were incorporated using dummy coding, while age was retained as a continuous variable. No transformations were performed, as no issues with linearity or extreme dispersion were identified. VIF values ranged from 1.09 to 1.26, with tolerances >0.79, indicating no relevant collinearity.

Additionally, since Poisson regression with robust variance does not directly allow estimation of certain classical diagnostic statistics (such as VIF or Durbin–Watson), an auxiliary linear model was implemented including the same matrix of independent variables used in the multivariable model. This approach was purely diagnostic and allowed evaluation of collinearity and error autocorrelation under a comparable structure. Results showed VIF values between 1.09 and 1.26 and a Durbin–Watson statistic of 2.035 ($p = 0.904$), suggesting absence of relevant collinearity and autocorrelation. Full results of the auxiliary model are presented in Figures 3 and 4.

Figure 3. Variance inflation factors (VIF)

Estadísticas de Colinealidad

	*VIF	Tolerancia
ENF RENAL	1.132	0.8835
GLP1	1.186	0.8429
EDUCACIÓN	1.168	0.8563
CÁNCER	1.177	0.8493
SEXO	1.093	0.9146
EDAD POLI	1.172	0.8534
DISLIPIDEMIA	1.151	0.8685
HIPOGLICEMIAS	1.197	0.8351

Fuente: Jamovi 4.2
*Factores de inflación de la varianza

Figure 4. Durbin-Watson Test

Prueba Durbin-Watson de Autocorrelación

Autocorrelación	Estadístico *DW	p
-0.04634	2.035	0.90400

Fuente: Jamovi 4.2
*Durbin-Watson

Discussion

In Colombia, flash continuous glucose monitoring became available starting in 2020, following official approval by the National Institute for Food and Drug Surveillance (INVIMA) (15). Consequently, evidence on the use of this device in the Colombian population remains limited, particularly regarding changes in glycated hemoglobin in patients with type 1 and type 2 diabetes after its implementation. Additionally, in the global literature, most studies have focused on patients with type 2 diabetes, highlighting the relevance of the findings of the present study.

In the analyzed population, glycated hemoglobin had an initial mean of 8.30% and decreased to 7.8% after device use, with a difference of 0.5%

between measurements. This result is similar to that reported in studies conducted in adolescents and young adults with type 1 diabetes (16), where baseline HbA1c was 8.9% and decreased to 8.5% at 26 weeks. It is worth noting that this study included a younger population than the present study, although sharing the common characteristic of type 1 diabetes.

Regarding hypoglycemia, a high frequency of this event was observed during the use of continuous glucose monitoring. In contrast, other studies have reported a reduction in hypoglycemic events, although with possible underestimation when based solely on emergency records or clinical history data (17). In the population from the analyzed healthcare institution, patients are monitored not only by physicians during consultations but also by a care and education team that conducts continuous follow-up of hospitalizations, reviews FGM reports, adjusts insulin therapy, and actively inquires about hypoglycemic episodes. This may explain the higher reporting of hypoglycemic events by the healthcare team.

Furthermore, in this study, only 6% of patients were receiving treatment with GLP-1 receptor agonists, all of whom had a diagnosis of type 2 diabetes mellitus. Although this proportion is low, it is consistent when compared with studies conducted in patients with type 2 diabetes in three European countries (18), where GLP-1 use was reported at 7.6% in Austria, 33% in France, and 11.5% in Germany.

The low proportion observed in our sample may be explained by two factors: first, most participants in the present study had a diagnosis of type 1 diabetes, a condition in which GLP-1 use is not routinely indicated due to its pathophysiology; and second, this is a high-cost medication whose prescription is subject to compliance with specific clinical criteria established by the healthcare provider institution (19).

A relevant finding was the impact of education on HbA1c changes, as 71.3% of patients who received at least one in-person educational session achieved a reduction in this marker. Similar results have been reported in studies on the use of FGM combined with diabetes education programs delivered via telemedicine in patients with type 1 diabetes (20), where HbA1c decreased from 7.9 ± 1.4% to 7.3 ± 1.1% at three months ($p < 0.01$).

In the multivariable analysis of this study, education and renal disease were the variables with the greatest explanatory weight regarding changes in HbA1c. The education variable showed a low VIF (1.168) and high tolerance (0.856), confirming the absence of collinearity and the validity of its in-

dependent effect. This result is consistent with previous studies (21), which reported that after six months of FGM use combined with an educational program, HbA1c decreased from 8.33% to 8.05%, confirming the relevance of structured diabetes education.

Regarding renal disease, different behavior was observed depending on the type of analysis. In the bivariate analysis, chronic kidney disease (CKD) behaved as a risk factor (RR = 2), whereas in the multivariable analysis it appeared as a protective factor (RR = 0.63). This discrepancy suggests the influence of confounding variables, which, once adjusted in the model, revealed the underlying association.

From a pathophysiological perspective, chronic kidney disease (CKD) may affect the accuracy of HbA1c as a marker of glycemic control. Factors such as reduced erythrocyte lifespan due to anemia secondary to erythropoietin deficiency, and the use of erythropoiesis-stimulating agents that generate younger erythrocytes less exposed to glucose, may lead to artificially low HbA1c values. Additionally, alterations in glucose metabolism inherent to CKD, such as decreased insulin clearance or variations in insulin sensitivity, contribute to glycemic fluctuations that HbA1c may not fully capture (22).

In CKD, an apparent association with a higher probability of HbA1c reduction was observed; however, this finding should be interpreted with caution, as HbA1c may underestimate true glucose levels in this population. In this context, it is recommended to complement metabolic assessment in patients with CKD using metrics such as time in range and glycemic variability to achieve a more accurate evaluation of glycemic control (23).

Additionally, approximately one in six patients had a history of cancer. In the adjusted model, a trend toward a lower probability of HbA1c change was observed (RR = 0.55; 95% CI: 0.27–1.03; p = 0.083), although it did not reach statistical significance. This finding may be related to the metabolic and therapeutic complexity inherent to oncological disease. Although the study was not designed to specifically analyze this interaction, it highlights the need for further research in populations with multimorbidity.

Among the strengths of the study is that it represents an institutional census conducted in a specialized diabetes care center, providing a relevant sample size in the Colombian context for a technology that remains underreported in the country. Additionally, the structured selection and follow-up process strengthened internal validity, and the use of a Poisson regression model with robust variance allowed appropriate estimation of adjusted relative risks for a retrospective cohort design.

Regarding limitations, the retrospective nature may introduce biases related to the quality of clinical records. Although no losses occurred in the final analyzed cohort, missing data were identified in less than 10% of some variables and were handled through simple imputation. Furthermore, as this was an institutional cohort without a formally standardized educational protocol, generalizability of the results should be interpreted with caution.

Overall, the findings suggest that improvement in glycemic control does not depend solely on access to technology but rather on its integration with educational interventions and continuous clinical follow-up. This combined model could be replicable in other institutions as a potentially cost-effective strategy, promoting better metabolic control and reducing the risk of long-term complications. Future studies should evaluate longer-term clinical outcomes and incorporate formal economic analyses within the Colombian context.

Conclusions

This study demonstrated that the implementation of flash glucose monitoring, within the context of a structured education program and multidisciplinary support, was associated with a significant improvement in glycemic control, achieved in more than 70% of the evaluated patients. These findings address the main objective of the study and reinforce the importance of integrating technological strategies with educational interventions to enhance clinical outcomes in individuals with diabetes.

These results are particularly relevant in a context where diabetes mellitus continues to represent a global and national challenge for healthcare systems. In this scenario, the incorporation of innovative technologies such as flash glucose monitoring constitutes an opportunity to optimize metabolic control (24). In the analyzed cohort—characterized by a younger population, predominantly female, and with a lower frequency of cardiovascular comorbidities compared to other studies—the device was associated with a significant reduction in HbA1c, consistent with findings reported in adolescents and young adults with type 1 diabetes mellitus (T1DM). However, this benefit was accompanied by a high frequency of hypoglycemic events, emphasizing the need for continuous education, close clinical follow-up, and active monitoring to maximize the safety and sustainability of treatment.

Finally, further research is required to explore these benefits in populations with complex comorbidities, such as chronic kidney disease, in order to refine the interpretation of metabolic outcomes.

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