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Gazira Diabetes Puzzle: *Logistic Regression Reveals Key Predictors of Type 1 Diabetes in Adolescents*

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Abstract :
Background: Type 1 diabetes (T1D) in adolescents poses a growing public health concern worldwide, particularly in low-resource settings such as Sudan, where fragile healthcare infrastructure, limited laboratory access, and ongoing conflict exacerbate management challenges. Understanding determinants of glycemic control is critical for designing targeted interventions. This study aimed to identify predictors of glycemic control among adolescents with Type 1 Diabetes (T1D) in Gazira State and to evaluate the performance of a logistic regression model in predicting outcomes.

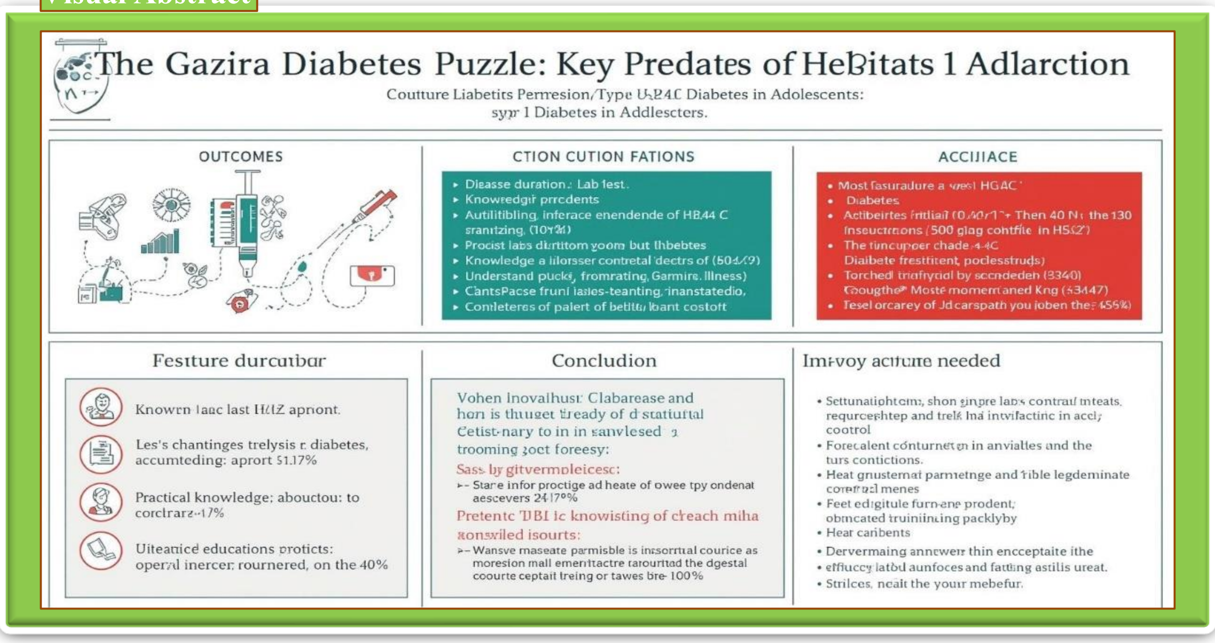
Methods: A cross-sectional study was conducted among 400 adolescents with type 1 diabetes mellitus (T1D) between 2020 and 2021. Data were obtained through structured questionnaires and clinical records. Glycemic control was assessed by HbA1c, categorized as controlled (< 7.5%) or uncontrolled (≥ 7.5%). Associations between sociodemographic, clinical, and knowledge-related factors and control status were examined using Chi-square tests. A binary logistic regression model was applied to identify independent predictors, with model fit evaluated using Hosmer–Lemeshow statistics and predictive accuracy assessed.

Results: Of the participants, 250 (62.5%) had uncontrolled HbA1c and 150 (37.5%) had controlled values. Disease duration was significantly associated with poor control ($\chi2 = 20.606$, $p = 0.015$). Knowledge-related factors showed strong effects: adolescents who knew their last HbA1c ($\chi2 = 83.115$, $p < 0.001$), understood HbA1c as an average glucose indicator ($\chi2 = 15.706$, $p < 0.001$), recognized vomiting as a ketoacidosis symptom ($\chi2 = 2.246$, $p = 0.019$), and tested more frequently when sick ($\chi2 = 4.245$, $p = 0.035$) were more likely to have controlled HbA1c. Logistic regression confirmed a good fit (Model $\chi2 = 98.924$, $p < 0.001$; Hosmer–Lemeshow $\chi2 = 0.839$, $p = 0.999$) with 95% overall accuracy, high specificity (98.7%) for uncontrolled cases, but low sensitivity (37.5%) for controlled cases. Independent predictors included frequency of HbA1c testing (OR = 2.29, $p = 0.034$), knowledge of own HbA1c result (OR = 2.65, $p < 0.001$), and knowledge to test more when ill (OR = 4.17, $p = 0.108$).

Conclusion: Most adolescents in Gazira had uncontrolled diabetes, with practical knowledge and disease duration as key determinants. Specific skills—such as HbA1c literacy and sick-day monitoring—were stronger predictors than general awareness. Improving adolescent-focused education, ensuring reliable HbA1c testing, and addressing systemic barriers are crucial to reducing the T1D burden in Sudan and similar contexts.

Keywords: Type 1 diabetes; adolescents; HbA1c; glycemic control

Visual Abstract



Introduction

Diabetes mellitus is a group of metabolic diseases characterized by high blood glucose levels resulting from defects in insulin secretion, insulin action, or both [1]. Glucose is derived from food intake, and insulin acts as the hormone facilitating its entry into cells for energy production [1].

The burden of diabetes has been increasingly documented worldwide. In specific populations, metabolic abnormalities such as lipid profile changes have been linked to poor glycemic control, reflecting the complexity and rising health burden of diabetes [2]. The prevalence of diabetes continues to grow, with projections indicating a significant rise in affected populations, particularly in low- and middle-income countries [3]. Lifestyle-related risk factors such as dietary changes and reduced physical activity further amplify the incidence of diabetes [4,5]. These lifestyle shifts have also contributed to growing pressure on healthcare systems, as observed in several regions, including the Middle East [6].

Despite ongoing advances, challenges remain. Many individuals with diabetes remain undiagnosed, and gaps in access to healthcare services are pronounced in resource-limited settings [6]. In Sudan, where conflict and displacement strain the health system, inadequate healthcare infrastructure and limited availability of specialized diabetes care exacerbate the risk of poor disease control [8]. Addressing these gaps requires targeted epidemiological studies that examine disease determinants in local contexts.

While Type 2 Diabetes accounts for most global cases, Type 1 Diabetes (T1D), an autoimmune disorder primarily affecting adolescents, represents a significant public health concern. The limited healthcare coverage and fragile systems in Sub-Saharan Africa, particularly in Sudan, highlight the urgent need for focused research and context-specific interventions [8]. This study aims to identify the key factors influencing the incidence of Type 1 Diabetes (T1D) among adolescents in Gazira State, Sudan, and to evaluate the suitability of the Logistic Regression Model for analyzing such epidemiological data. The findings are expected to inform effective prevention, early detection, and management strategies, thereby reducing the disease burden and improving health outcomes in this vulnerable population.

Literature Review

Type 1 Diabetes (T1D) arises from a multifactorial aetiology, with genetic, environmental, and immunological factors contributing to disease onset [9]. While global studies describe variations in incidence across age groups and populations, Sub-Saharan Africa continues to face a significant knowledge gap due to the limited availability of epidemiological data [10,11]. This lack of region-specific evidence restricts the development of effective, targeted public health strategies.

In many African contexts, limited access to healthcare services and specialised treatment further complicates disease management and negatively impacts patient outcomes [12]. Socioeconomic barriers, including poverty, displacement, and instability, have been recognized as major contributors to poor chronic disease control, placing adolescents at heightened risk for T1D complications [13,14]. The increasing prevalence of diabetes in Sub-Saharan Africa, particularly Type 2 driven by rapid lifestyle transitions, highlights the broader need for comprehensive research in the region, even as T1D presents distinct challenges [9,11,13].

Community-level perceptions of diabetes risk and prevention significantly influence health behaviours and the adoption of interventions. Studies from Sub-Saharan Africa demonstrate that cultural and social contexts shape awareness and prevention strategies, underscoring the importance of locally adapted public health campaigns [15]. In Sudan, the situation is compounded by conflict-driven displacement, which has been linked to psychological distress and disrupted access to healthcare, further aggravating disease vulnerability [14,16].

The coexistence of mental health conditions, such as depression, among displaced populations may also influence glycemic control and long-term disease progression in adolescents with T1D [16,17].

Healthcare infrastructure remains a critical determinant of diabetes outcomes. In resource-limited settings, such as Sudan, constraints in laboratory services, continuity of care, and treatment availability often hinder early diagnosis and effective management [12,14]. The psychosocial burden of living with T1D during adolescence, particularly when compounded by socioeconomic stressors, has been shown to affect adherence to treatment regimens and overall quality of life [17].

Given these complexities, robust epidemiological methodologies are crucial for understanding the determinants of T1D in such settings. Logistic regression analysis has long been employed in chronic disease research to identify risk factors, account for confounding variables, and assess model fit [18]. Applying this approach to the context of adolescent T1D in Sudan provides an opportunity to identify predictive factors and guide evidence-based interventions in vulnerable populations.

Objectives

This study had two primary objectives:

(1) to identify the main factors influencing the incidence and glycemic control of Type 1 diabetes among adolescents in Gazira State, Sudan; and

(2) to evaluate the suitability of a binary logistic regression model for analyzing these factors and predicting diabetes control outcomes.

Results

The results are organized in two parts. First, bivariate associations between HbA1c control status and various factors are examined using Chi-square tests. This addresses Objective 1 by highlighting potential risk factors for poor glycemic control. Second, a multivariate analysis using binary logistic regression identifies independent predictors of HbA1c control and assesses model performance, directly addressing Objective 2.

Bivariate Analysis (Chi-Square Tests)

Family Environment Factors: Neither family support nor family history of diabetes showed a significant association with glycemic control. As shown in **Table 1**, patients with and without adequate family support had similar rates of uncontrolled HbA1c (χ^2 = 3.140, p = 0.371). Likewise, a positive family history of diabetes did not significantly influence HbA1c control (χ^2 = 2.939, p = 0.072).

Table 1. χ^2 Test – **HbA1c and the Patient's Family Environment**

Variables	χ^2	df	*P*-value
Patient's family support	3.140	3	0.371
Family history of diabetes	2.939	1	0.072

Duration of Diabetes and Complications:

The duration of Type 1 diabetes was significantly associated with HbA1c control (χ^2 = 20.606, p = 0.015), indicating that longer disease duration is linked to a higher likelihood of uncontrolled HbA1c (**Table 2**). In contrast, other factors such as having "good" diabetes experience, the presence of diabetes-related complications, or the type of complications showed no significant associations (all $p>0.3$). These results suggest that the **duration of illness** is a significant risk factor for poor control. In contrast, the mere presence of complications or patient-reported experiences alone does not distinguish between controlled and uncontrolled cases.

Table 2. χ^2 Test – **HbA1c and the Patient's Duration of Diabetes**

Variables	χ^2	df	*P*-value
Duration of Type 1 diabetes	20.606	1	0.015 **
"Good" experience of diabetes	2.939	1	0.398
Presence of diabetes complications	0.464	1	0.333
Type of complications	7.023	9	0.635

Insulin Treatment and Adherence:

Table 3 summarises the association between treatment-related factors and HbA1c control. The insulin dosage (per kilogram body weight) was not significantly different between the controlled and uncontrolled groups (χ^2 = 1.249, p = 0.184). Similarly, recent adherence issues – such as missing prescribed insulin doses in the last 3 months (χ^2 = 0.258, p = 0.780) – and insulin storage practices at home (χ^2 = 0.995, p = 0.346) were not associated with HbA1c outcomes. These findings suggest that, within this cohort, **factors related to insulin regimen** and short-term non-adherence did not have a measurable impact on glycemic control. However, this does not preclude their clinical significance on an individual level.

Table 3. χ^2 Test – **HbA1c and the Patient's Insulin Treatment Plan**

Variables	**χ^2**	**df**	***P*-value**
Insulin dosage per kg body weight	1.249	1	0.184
Missed prescribed insulin doses (last three mo)	0.258	1	0.780
Insulin home storage (appropriate vs. not)	0.995	2	0.346

Patient Diabetes Knowledge:

In total, 12 questions assessed the patients' knowledge related to diabetes. Chi-square analysis revealed that only 4 of these 12 knowledge items were significantly associated with HbA1c control (see Table 4). Adolescents who knew their most recent HbA1c result had substantially better control than those who did not (χ^2 = 83.115, p < 0.001). Knowing to increase blood glucose monitoring during intercurrent illnesses (such as a flu) was also linked to better control (χ^2 = 4.245, p = 0.035). Recognizing vomiting as a sign of diabetic ketoacidosis (DKA) was significantly associated with HbA1c status (χ^2=2.246, p=0.019). Finally, understanding that HbA1c reflects average blood glucose over the past 2–3 months (approximately 6–12 weeks) was strongly associated with reasonable control (χ^2 = 15.706, p < 0.001). The remaining knowledge questions (for example, causes of high glucose, handling mild hypoglycemia, foot care, chronic complications, and effects of exercise) did not show significant differences between the controlled and uncontrolled groups (p > 0.1

for each). These results highlight that gaps in critical diabetes knowledge — particularly related to monitoring and interpreting HbA1c are common among adolescents with uncontrolled diabetes, underlining patient education as a key factor in disease management.

Table 4. χ^2 Test – **HbA1c and Patient's Diabetes Education (Knowledge)**

	χ^2	df	*P*-value
Knows the last HbA1c result	83.115	1	0.000 **
High blood glucose levels can be caused by insufficient insulin production.	0.348	1	0.361
Treating a beginning low blood glucose with juice?	1.047	1	0.248
Test blood glucose more often when sick (flu)?	4.245	1	0.035 *
Vomiting is a sign of DKA?	2.246	1	0.019 **
What is the best foot care? Is it daily inspection & wash?	0.230	1	0.400
Lung problems are unrelated to diabetes?	0.094	1	0.477
Numbness/tingling can indicate nerve damage.	0.084	1	0.500
Infections typically raise blood glucose levels.	0.569	1	0.311
Does exercise lower blood glucose in individuals with good blood glucose control?	0.826	1	0.258
HbA1c reflects avg. glucose over the past 6–12 weeks?	15.706	1	0.000 **
Milk is the food highest in fat (among options)?	0.414	1	0.342

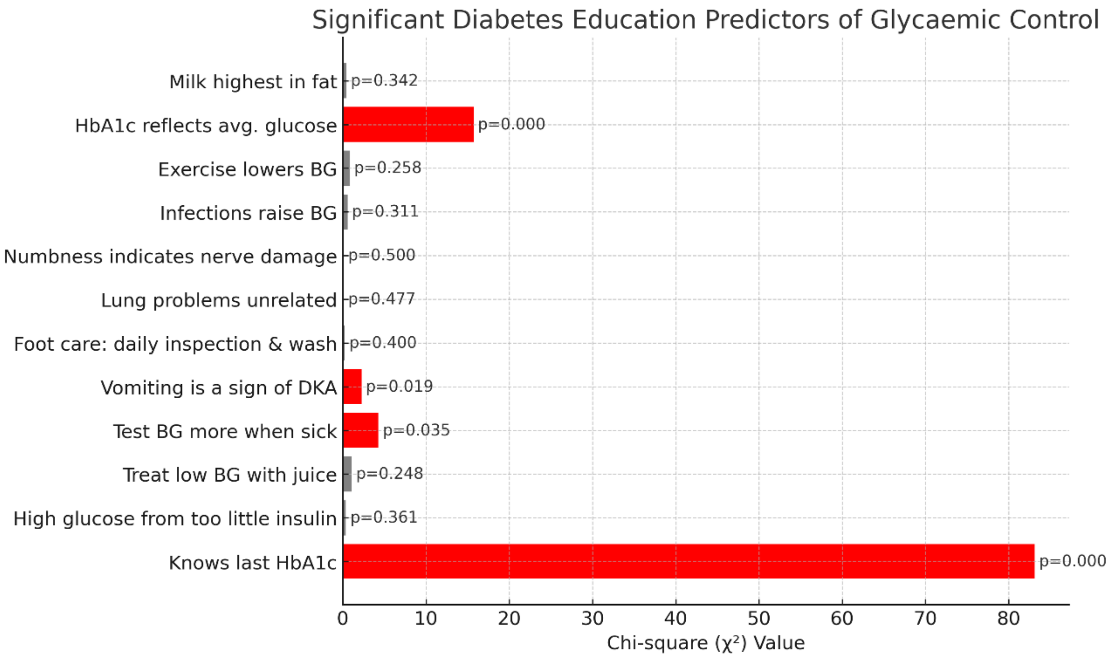


Figure 2. Chi-square analysis of diabetes education questions associated with glycaemic control among adolescents with Type 1 diabetes in Gazira State, Sudan (2020–2021). Significant predictors ($p<0.05$) are highlighted in red."

- **Red bars = significant predictors ($p<0.05$)**
- **Grey bars** = non-significant
- Labels show the exact *p*-values for clarity

Multivariate Analysis (Logistic Regression)

To address Objective 2, a binary logistic regression model was fitted with "HbA1c control" (controlled = 1, uncontrolled = 0) as the dependent variable. Multiple predictors were entered, including sociodemographic factors, clinical history, and the diabetes knowledge variables examined above. The results of the logistic regression are presented in Tables 5–8.

Overall Model Fit: As shown in **Table 5**, the logistic model was statistically significant (Model χ^2 = 98.924, df = 28, $p < 0.001$), indicating that the set of predictors reliably distinguishes between controlled and uncontrolled diabetes cases. The Nagelkerke R^2 for the model (not shown in the table) was also high, suggesting a good amount of variance explained by these variables.

Table 5. Logistic Regression Model Fit (Chi-square Test)

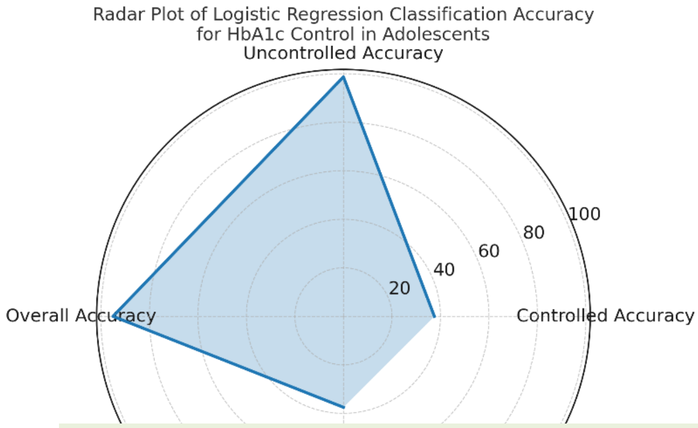
	Chi-square	df	Sig.
Step 1	98.924	28	**0.000**
Block	98.924	28	**0.000**
Model	**98.924**	**28**	**0.000**

Predictive Accuracy:

The model's classification performance is summarised in Table 6. Out of 24 cases that had controlled HbA1c in reality, only nine were correctly predicted (sensitivity for "controlled" = 37.5%), reflecting the difficulty in predicting which patients achieve control. However, of the 376 truly uncontrolled cases, 371 were correctly predicted as uncontrolled (specificity ≈ 98.7%). The overall accuracy of the model was 95.0%. This high overall accuracy is driven by the large proportion of uncontrolled cases, which the model predicts very well; however, the lower sensitivity indicates room for improvement in identifying the smaller group of controlled patients.

Table 6. Logistic Regression Classification Table

	Predicted Controlled	Predicted Uncontrolled	% Correct
Controlled (n=24)	9	15	37.5%
Uncontrolled (n=376)	5	371	98.7%
Overall			**95.0%**



Caption: *Radar chart comparing observed and predicted outcomes of HbA1c control among adolescents in Gazira State, Sudan. The model achieved 37.5% accuracy in detecting controlled cases, 98.7% accuracy in detecting uncontrolled cases, and an overall accuracy of 95.0%.*

Figure 1: Radar Plot of Logistic Regression Classification Accuracy for HbA1c Control in Adolescents with Type 1 Diabetes"

Goodness-of-Fit:

The Hosmer–Lemeshow goodness-of-fit test (Table 7) yielded a χ^2 value of 0.839 with 8 degrees of freedom, and a p-value of 0.999. This non-significant result ($p > 0.05$) indicates that the logistic model's estimates fit the observed data well. In other words, there is no evidence of lack of fit – the model's expected frequencies for controlled/uncontrolled status closely match the observed frequencies across subgroups of the data.

Table 7. Hosmer–Lemeshow Test for Logistic Model Fit

Step	Chi-square	df	Sig.
1	0.839	8	0.999

Key Predictors of Glycemic Control:

The regression coefficients, significance levels, and odds ratios (Exp(B)) for all candidate predictors are detailed in Table 8. Seven variables emerged as notable predictors of HbA1c control ($p<0.05$ or as indicated):

- Diabetic experience: Adolescents who reported having more extensive experience in managing their diabetes tended to have better control (B = 1.029, Exp(B) = 2.799), although this variable's p-value (0.154) was marginal in the model. The direction suggests that each incremental improvement in "experience" (as subjectively measured) nearly triples the odds of reasonable control.

- **Frequency of HbA1c testing:** Individuals who had their HbA1c tested multiple times in the past year were significantly more likely to be in the controlled group (B = 0.830, p = 0.034). Specifically, the odds of reasonable control were 2.294 times higher for patients who underwent repeated HbA1c tests compared to those who did not undergo these tests. This aligns with the idea that regular monitoring is associated with better management.
- **Knowledge of HbA1c result:** Knowing one's own most recent HbA1c result was one of the strongest independent predictors of control (B=0.974, p<0.001). The odds of achieving control were **2.65 times higher** for patients who were aware of their HbA1c value, controlling for other factors. This underscores the importance of patient awareness and engagement in care.
- **Diabetes education variables:** Four specific knowledge questions remained in the final model (Edu1, Edu2, Edu9, Edu10), each corresponding to one of the significant items identified in the chi-square analysis (see Table 4). The effects of these are reflected in their Exp(B) values: for instance, "Edu2" (Exp(B)=4.168) suggests that correct knowledge in that item quadrupled the odds of control, whereas "Edu1" and "Edu10" had Exp(B) < 1, implying that lack of knowledge in those areas drastically reduced the odds of control. Collectively, these education-related predictors indicate that **overall diabetes knowledge is a crucial determinant** of glycemic control.

Conversely, several factors did not show significant independent effects in the multivariate model. These include family support, family history of diabetes, family income level, participation in sports (physical activity), presence of diabetes complications, insulin dosage, and routine of home glucose monitoring (daily testing frequency and usage of a home glucose meter). Their p-values all exceeded 0.1 (Table 8), suggesting that once other factors are accounted for, these variables do not independently explain variance in HbA1c control among this cohort.

Table 8. Logistic Regression Coefficients (Variables in the Equation)

Predictor (Factor)	B	S.E.	Wald	df	Sig.	Exp(B)
Family sport (regular exercise)	-0.098	0.649	0.023	1	0.879	0.906
Family income (low vs. high)	0.025	1.156	0.000	1	0.983	1.025
Family support (adequate vs. not)	0.652	0.700	0.866	1	0.352	1.919
Family history of diabetes	0.641	0.716	0.802	1	0.370	1.899
Duration of illness (years)	0.621	0.548	1.288	1	0.256	1.862
Diabetic experience (self-rated)	1.029	0.721	2.036	1	0.154	2.799
Any diabetes complications	-0.070	1.007	0.005	1	0.944	0.932
Type of complications (micro/macro)	0.038	0.267	0.021	1	0.886	1.039
Insulin dosage (per kg body wt.)	0.525	0.772	0.463	1	0.496	1.690
Use of a home glucose meter	0.063	1.027	0.004	1	0.951	1.066
Daily home glucose measurements	-0.581	0.563	1.067	1	0.302	0.559
HbA1c tests per year (≥2 vs. <2)	0.830	0.392	4.478	1	0.034	2.294
Knowledge of one's own HbA1c result	0.974	0.186	27.317	1	0.000	2.650
Edu1: Knew last HbA1c result	-1.152	0.754	2.335	1	0.126	0.316
Edu2: Knew to test more when ill	1.427	0.887	2.588	1	0.108	4.168
Edu3: Knew how to treat low BG	-0.839	0.777	1.165	1	0.281	0.432
Edu4: Knew foot care rule	-0.913	0.936	0.951	1	0.329	0.401
Edu5: Knew if insulin lack causes high BG	-0.011	0.859	0.000	1	0.990	0.989
Edu6: Knew lung problems unrelated	-0.339	0.961	0.124	1	0.724	0.713
Edu7: Knew about neuropathy symptoms	-0.180	0.752	0.057	1	0.811	0.835
Edu8: Knew infection raises glucose	-0.570	1.133	0.253	1	0.615	0.566
Edu9: Exercise lowers glucose	1.000	0.800	1.562	1	0.211	2.719
Edu10: Knew the fat content of milk	-1.027	0.692	2.204	1	0.138	0.358
Edu11: Knew DKA sign (vomiting)	-0.760	1.686	0.203	1	0.652	0.468
Edu12: Other knowledge item	-0.111	1.270	0.008	1	0.931	0.895

Note: "Edu1"–"Edu12" correspond to the 12 diabetes knowledge questions listed in Table 4. Here, positive B coefficients indicate that better knowledge is associated with higher odds of control, while negative B coefficients indicate the opposite. For example, Edu2 (knowing to test more when sick) has a B-value of 1.427, an Exp(B) of 4.168, suggesting a substantial positive impact of that knowledge on control. Edu1 and Edu10 have negative coefficients, implying that a lack of knowledge in those areas dramatically lowers the odds of control.) In summary, the multivariate analysis confirms **Objective 1** by pinpointing the most influential factors for poor glycemic control: insufficient patient knowledge (especially about HbA1c and sick-day management) and longer disease duration are associated with uncontrolled HbA1c, whereas proactive health behaviours (frequent HbA1c testing, awareness of results, accumulated management experience) favour better control. The logistic regression results also fulfil **Objective 2**, demonstrating that a logistic model is suitable for this analysis—it achieved a high overall accuracy (95%) and showed an excellent fit. These findings underscore the need for improved diabetes education and regular monitoring to enhance glycemic control among adolescents in this setting.

Discussion

This study among adolescents with Type 1 diabetes in Gazira State highlights a substantial burden of suboptimal glycaemic control, with nearly two-thirds classified as uncontrolled and a logistic regression model that, while showing excellent overall fit and very high specificity for uncontrolled status, struggled to identify the much smaller controlled group. These findings are consistent with what Camara et al. said, namely that poor glycaemic control in Sub-Saharan Africa is often tied to systemic barriers such as limited access to HbA1c testing [19].

In our cohort, specific knowledge elements—knowing one's latest HbA1c, understanding that HbA1c reflects average glycaemia, and applying "sick-day" monitoring—were strongly linked to glycaemic control. Banca et al. said that frequent blood glucose monitoring remains a critical determinant of improved control in youth with Type 1 diabetes [20]. Similarly, Channon et al. said that adolescent-centred counselling interventions can strengthen engagement and adherence, which resonates with our finding that targeted knowledge is key to management success.

At the community level, Manyara et al. said that local perceptions of diabetes risk and prevention directly shape behaviour. Our findings suggest that turning these perceptions into concrete actions—such as intensifying monitoring during illness—can yield meaningful improvements. Meetoo observed that dietary self-care patterns vary significantly between ethnic groups, which reinforces the importance of designing culturally tailored interventions [21].

System-level barriers were also evident in our results. Idemyor said that persistent weaknesses in Sub-Saharan health systems compromise diabetes outcomes, which explains why family support and insulin dosing were not significantly associated with control in our study. Razan et al. reported that service disruptions in Sudan, aggravated by conflict and displacement, reduce continuity of care. At the same time, Ahmed and Johnson said that depression is common among displaced populations, compounding disease burden. Together, these findings suggest that psychosocial stress and health service disruptions can blunt the effects of family or clinical support when self-care knowledge is insufficient.

Alotaibi and Glezeva both said that the diabetes burden across the Middle East and Africa is rising rapidly, demanding urgent and scalable strategies. Parker stated that prevention efforts in resource-limited settings must be community-based and context-specific [22]. This supports our practical recommendations: routinising HbA1c disclosure and interpretation at each test, embedding short "sick-day" education modules in schools and clinics, and safeguarding access to monitoring supplies even under stress on the supply chain. These suggestions align with the adolescent-focused approaches of Channon et al. and the humanitarian recommendations of Razan et al.

From a methodological standpoint, our logistic regression model demonstrated excellent fit. Hosmer et al. stated that assessing calibration through the Hosmer–Lemeshow test is crucial for validating logistic models [18]. McQueen emphasized that rigorous epidemiological modelling is essential in global chronic disease prevention [23], and our findings illustrate the utility of such models for identifying high-yield predictors of glycaemic control. However, the imbalance in outcome groups—many more uncontrolled than controlled—explains the model's very high specificity but weak sensitivity. Future studies should therefore incorporate balanced metrics and consider predictor sets focusing on the most impactful variables.

Prolonged disease duration was associated with poorer control in our data. Ramachandran said that the rising prevalence and duration of diabetes in Asian countries are strongly linked to worsening complications [24]. Nègre-Salvayre et al. documented the cumulative oxidative stress and metabolic damage caused by chronic hyperglycaemia [1]. Both perspectives reinforce our finding that more prolonged exposure increases vulnerability, requiring booster education, psychosocial support, and regular follow-up to mitigate fatigue and prevent deterioration.

Strengths and limitations. A strength of this study is its focus on an under-represented adolescent group, integrating behavioural and clinical predictors. Bonisteel et al. said that careful recruitment and sustained engagement are essential for research involving vulnerable groups [25], and our approach reflected these principles through community-based enrolment. Limitations include reliance on self-reported behaviours, residual confounding, and outcome imbalance, which reduced model sensitivity for controlled cases.

Implications. Indrahadi et al. said that socioeconomic inequalities are a major driver of diabetes prevalence in Indonesia [26]. Our findings parallel this by showing that in Gazira State, structural and knowledge-related barriers outweigh other determinants. Embedding simple, teachable skills—such as interpreting HbA1c results and monitoring blood sugar more frequently when ill—into schools, clinics, and humanitarian health services can provide immediate benefits. Grant said that management in resource-poor settings must focus on context-specific and cost-effective strategies [27]. This makes micro-interventions a feasible path to improving adolescent outcomes in Sudan and comparable regions.

Conclusion

This study demonstrated that the majority of adolescents with Type 1 diabetes in Gazira State had uncontrolled glycaemic status, reflecting both systemic health service gaps and individual knowledge-related barriers. The logistic regression model performed well overall but was limited by class imbalance, showing high specificity for uncontrolled cases while under-detecting the smaller controlled group. The most influential determinants of glycaemic control were practical knowledge factors, particularly awareness of HbA1c values, understanding of their clinical significance, and adherence to sick-day monitoring.

These findings highlight that in resource-limited and conflict-affected settings, relatively teachable and straightforward skills can have a substantial impact on diabetes outcomes. Strengthening patient education, ensuring consistent access to basic monitoring tools, and integrating adolescent-focused counselling into schools and primary care may yield immediate improvements. Addressing the effects of longer disease duration will require periodic booster education and psychosocial support, given the cumulative challenges of sustained self-management.

From a public health perspective, this research highlights the importance of context-specific strategies for managing chronic diseases in Sudan. Policymakers should prioritize targeted diabetes literacy programs, reliable supply chains for essential monitoring equipment, and accessible counselling services. For researchers, future longitudinal and interventional studies are needed to evaluate the effectiveness of micro-interventions, overcome methodological challenges such as outcome imbalance, and expand the evidence base for adolescent diabetes care in Sub-Saharan Africa.

Ultimately, this study provides actionable insights for healthcare providers and decision-makers, offering a pathway to reduce the burden of Type 1 diabetes among adolescents in Gazira State through cost-effective, culturally relevant, and sustainable interventions.

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