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LONG-TERM REAL WORLD OUTCOMES OF CONTINUOUS ENGAGEMENT AND RE-ENGAGEMENT IN A DIGITAL DIABETES REVERSAL PROGRAM

Endocrinology

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ABSTRACT

Background: Lifestyle modifications are integral to the effective management of type 2 diabetes (T2D), contributing to improved glycemic control, weight regulation, and overall metabolic outcomes. However, the long-term sustainability of these benefits remains a significant challenge, as patient engagement often varies dynamically over time. In this context, structured and continuous support becomes essential for maintaining clinical gains. This study aimed to evaluate the role of SugarFit's structured, technology-enabled support system in sustaining diabetes-related improvements by examining longitudinal changes in glycated hemoglobin (HbA1c), fasting blood sugar (FBS) and weight. **Aim of the study:** To evaluate the long term impact of continuous participation and re-engagement in a structured, technology-enabled diabetes management program on glycemic control and metabolic outcomes in individuals with T2D.**Objective:** To assess and compare longitudinal changes in HbA1c, fasting blood sugar and weight among individuals with continuous engagement versus those who discontinued and later re-engaged in the program.**Methodology:** A retrospective analysis was conducted on 785 individuals enrolled in the SugarFit Diabetes Reversal and Management Program (SDRMP) over 3 years, stratified into two equal cohorts: Cohort 1 (n=405; Male/Female: 281/124; Duration of diabetes: 10.9 ± 7.7 years; Age: 52.7 ± 11.1 years; Individuals with consistent program participation throughout the study, with assessments at 12 months (year 1), 24 months (year 2), and 36 months (year 3)) and Cohort 2 (n=380, Male/Female: 292/88; Duration of diabetes: 11.2 ± 7.6 years; Age: 51.91 ± 10.91 years; Individuals with initial participation during months 0-12 (year 1), subsequent discontinuation during months 13-24 (year 2), and eventual re-initiation of participation with follow-up extending to 36 months (year 3) in the program). Participants received structured interventions targeting diet, physical activity, and mental wellness, supported by tech-driven, real-time behavioral coaching and immediate clinical guidance from a multidisciplinary team comprising general physicians and certified health coaches. Patterns of continuous participation and re-initiation were systematically evaluated, alongside longitudinal changes in HbA1c, FBS and weight. Statistical analyses were performed with a significance level set at $p < 0.05$.**Results:** In Cohort 1, participants demonstrated sustained improvements from baseline through long-term follow-up (3 years), with mean HbA1c decreasing from 10.78 ± 5.28% to 7.29 ± 1.18% at the end of Year 1 and remaining stable through Year 2 (7.19 ± 1.13%) and Year 3 (7.20 ± 1.11%), indicating durable glycemic control. FBS demonstrated a progressive decline across timepoints (Baseline: 144.02 ± 39.07 mg/dL; Year 1: 138.17 ± 43.02 mg/dL; Year 2: 130.85 ± 33.65 mg/dL; Year 3: 129.19 ± 29.35 mg/dL), while body weight exhibited a comparable trajectory (Baseline: 75.09 ± 14.10 kg; Year 1: 72.54 ± 12.73 kg; Year 2: 72.88 ± 13.20 kg; Year 3: 72.20 ± 12.69 kg), indicating durable metabolic control. In Cohort 2, initial improvements from baseline during the first year of participation were observed across all parameters (HbA1c: 8.83 ± 1.76% to 7.43 ± 1.35%; FBS: 137.32 ± 38.50 mg/dL to 135.85 ± 35.74 mg/dL; weight: 76.18 ± 14.73 kg to 74.46 ± 14.51 kg). These improvements were followed by deterioration during the discontinuation phase (HbA1c: 8.29 ± 1.81%; FBS: 150.14 ± 49.70 mg/dL; weight: 74.51 ± 15.15 kg). Following subsequent resumption of participation, significant improvements were re-established (HbA1c: 7.61 ± 1.31%; FBS: 142.87 ± 43.96 mg/dL; weight: 72.77 ± 12.63 kg), demonstrating restoration of metabolic control with re-initiation of structured intervention. All observed changes across parameters were statistically significant ($p < 0.05$).**Conclusion:** Continuous participation in a structured lifestyle intervention program is strongly associated with sustained glycemic and metabolic stability in T2D. Participants who remained engaged for three consecutive years maintained stable outcomes, while those who discontinued experienced deterioration that substantially improved after re-engagement within the same year. These findings demonstrate that ongoing, technology-enabled coaching and clinical oversight are critical for maintaining long-term control and can effectively restore metabolic health after periods of disengagement, underscoring the essential role of sustained program participation in real-world diabetes management.

KEYWORDS

Type 2 Diabetes, Lifestyle Modifications, Continuous Engagement, Sustained Glycemic And Metabolic Stability.

INTRODUCTION

Type 2 diabetes mellitus (T2DM) evolves through a gradual disruption of metabolic homeostasis, where impaired insulin action, declining pancreatic β-cell function, and persistent elevations in blood glucose collectively drive disease progression [1-3]. These metabolic alterations are not isolated biological events but are profoundly shaped by modifiable behavioral factors, including dietary patterns, physical inactivity, and excess adiposity [4]. Within this context, lifestyle management assumes a central role in diabetes care, as it directly influences the underlying mechanisms contributing to disease progression. Interventions targeting nutrition, physical activity, and behavioral patterns have consistently demonstrated their potential to enhance insulin sensitivity, reduce glycemic burden, and support weight regulation, thereby improving overall clinical outcomes [5].

Building upon this mechanistic understanding, lifestyle-based strategies form an essential component of diabetes care, encompassing diabetes self-management education and support, medical nutrition therapy, structured physical activity, smoking cessation, and psychosocial care [6,7]. These elements function in an integrated manner rather than as isolated interventions, requiring active collaboration between patients and care providers. Such a coordinated approach is critical from the time of initial comprehensive evaluation and must be sustained across follow-up visits, complication screening, and the management of comorbid conditions to ensure long-term effectiveness [8].

Despite notable advancements in diabetes care that have improved the achievement of early glycemic control, the durability of these outcomes in real-world settings remains uncertain. This highlights a fundamental challenge in diabetes management, where long-term success depends less on the initiation of therapeutic strategies and more on the consistency of behavioral adaptation over time [9]. Although initial improvements in glycemic and anthropometric

parameters are frequently observed, maintaining these benefits remains difficult. Over time, reduced adherence can lead to the re-emergence of underlying metabolic disturbances, resulting in progressive deterioration of glycemic control. Thus, the effectiveness of lifestyle interventions is inherently tied not only to their implementation but also to their sustained continuation [10].

In this regard, long-term behavioral change rarely occurs without structured support and ongoing guidance. Continuous engagement within lifestyle intervention programs plays a pivotal role in reinforcing adherence, maintaining behavioral consistency, and preventing relapse [9,11]. Conversely, interruptions in such support systems may contribute to disengagement, diminished adherence, and worsening clinical outcomes. While the importance of lifestyle interventions is well established, existing literature has largely focused on short-term efficacy, with limited exploration of long-term engagement patterns. In real-world practice, patient participation is inherently dynamic, often characterized by phases of engagement, discontinuation, and re-engagement. However, the impact of these fluctuating patterns on the durability and potential reversibility of metabolic outcomes remains inadequately understood [11].

To further contextualize these patterns, a behavioral science perspective provides important mechanistic insight. The patterns of engagement and disengagement in lifestyle interventions can be interpreted through the lens of social cognitive theory, which emphasizes the interaction between individual factors, behavior, and environmental influences. Key constructs such as health knowledge, self-efficacy, self-regulatory capacity, and perceived barriers play a central role in both the initiation and maintenance of behavior change. Structured lifestyle programs are designed to strengthen these domains through continuous education, goal setting, self-monitoring, and feedback [12]. However, in the absence of sustained support, these constructs may weaken over time, leading to reduced adherence, loss of behavioral control, and subsequent deterioration in clinical outcomes. In this context, re-engagement may represent a reactivation of these behavioral mechanisms, enabling individuals to regain control and restore previously achieved metabolic improvements [13].

This understanding necessitates the evaluation of intervention models that can effectively accommodate the dynamic and non-linear nature of real-world patient engagement. In response to these challenges, digital health-enabled programs have emerged as scalable solutions capable of delivering continuous, adaptive, and personalized care. The SugarFit Diabetes Reversal and Management Program (SDRMP) represents one such comprehensive lifestyle intervention, integrating personalized nutrition, guided physical activity, continuous monitoring, and behavioral coaching within a flexible framework. Notably, the program supports both sustained engagement and structured re-engagement following periods of discontinuation, thereby offering a unique opportunity to examine how varying engagement trajectories influence long-term outcomes.

Therefore, the present study aims to investigate patterns of continuity and re-engagement among individuals enrolled in SDRMP and to evaluate their association with changes in key clinical parameters, including glycated hemoglobin (HbA1c), fasting blood sugar (FBS) and weight. Additionally, the study explores the influence of demographic factors and medication burden on these outcomes, with a particular emphasis on understanding the role of sustained support and structured guidance in achieving long-term success in diabetes management.

METHODOLOGY

Study Design and Setting

This study was a retrospective, real-world observational analysis conducted over a 3-year period among individuals enrolled in the SugarFit Diabetes Reversal and Management Program (SDRMP), a technology-enabled, structured lifestyle intervention platform designed for the management of T2D. The program integrates digital health tools with multidisciplinary clinical oversight to deliver personalized care at scale.

Study Criteria

Participants were eligible for inclusion if they were diagnosed with T2D with a baseline HbA1c ≥6.5%, aged ≥18 years, representing a population with uncontrolled diabetes suitable for structured lifestyle intervention. They were further required to have longitudinal program data reflecting either continuous participation over a 3-year period or patterns of discontinuation followed by subsequent re-engagement, enabling evaluation of real-world engagement trajectories. Individuals were excluded if they had advanced diabetes-related complications, including end-stage renal disease or severe cardiovascular conditions that could significantly influence metabolic outcomes, or if they were concurrently participating in other structured diabetes management programs during the study period to avoid potential intervention overlap. Additionally, participants with any acute medical condition requiring hospitalization within three months prior to enrolment were excluded. These criteria were applied to ensure a clinically stable population and to enable accurate evaluation of long-term outcomes associated with continuous engagement and re-engagement in a digital diabetes reversal program.

PICOT Framework

To ensure a structured and clinically interpretable assessment of clinical outcomes associated with continuous and discontinuous participation, the research question and analytical framework of the present study were organized using the PICOT (Population, Intervention, Comparison, Outcome, and Time) framework. The PICOT framework, originally described in evidence-based medicine by Richardson et al. (1995), is widely applied in clinical research to enhance methodological clarity by explicitly defining key study components and aligning research objectives with outcome assessment.

Within the context of this retrospective, real-world study, the PICOT framework was specifically adapted to capture the dynamic nature of patient engagement, including continuous participation and discontinuation followed by re-engagement in a digital diabetes reversal program. This structured approach facilitated a systematic evaluation of both the sustainability and potential restoration of glycemic and metabolic outcomes over a multi-year follow-up period.

PICOT Component	Description	PICOT Question
Population (P)	Adults with T2D enrolled in SDRMP	How do varying patterns of engagement, including continuous participation and discontinuation followed by re-engagement, in SDRMP influence the sustainability and restoration of glycemic control and metabolic outcomes over a long-term follow-up period in adults with T2D?
Intervention (I)	Continuous participation in a structured, tech-enabled lifestyle intervention program	
Comparison (C)	Intermittent participation, discontinuation, and re-engagement	
Outcome (O)	Improvement in HbA1c, FBS and weight	
Time (T)	Long-term follow-up up to 36 months (3 years), including continuous participation throughout the study period in Cohort 1 (assessments at 12 months (year 1), 24 months (year 2), and 36 months (year 3)), and in Cohort 2 an initial participation phase during months 0-12 (year 1), a discontinuation phase during year 2 (months 13-24), and re-initiation with follow-up extending to 36 months (year 3).	

Population (P):

Adults diagnosed with T2D enrolled in SDRMP between June 2021 and March 2026. A total of 785 participants were included and stratified into two cohorts based on engagement patterns:

Cohort 1 (Continuous engagement; n = 405): Individuals with sustained participation throughout the study duration.

Cohort 2 (Intermittent/re-engagement; n = 380): Individuals with initial participation, subsequent discontinuation, and eventual re-initiation of the program.

Intervention (I):

Participants received structured, technology-enabled lifestyle interventions targeting dietary modification, physical activity, and

mental wellness. Delivered via a digital platform with real-time tracking, integrated data analytics, and algorithm-driven personalization, these interventions were overseen by a multidisciplinary team of general physicians and certified health coaches to ensure timely and individualized guidance. This integrated model enabled continuous data capture, real-time interpretation, and dynamic adjustment of interventions, ensuring responsiveness to both metabolic status and behavioural patterns over time, while maintaining consistency across diverse participant profiles.

At initiation, CGM devices were provided for real-time glycemic pattern assessment. CGM data were continuously integrated with dietary, physical activity, and behavioural inputs within a unified analytics framework, enabling dynamic adjustments to interventions based on individual glycemic variability and response patterns. This data-driven approach facilitated early identification of deviations, including postprandial excursions and rising variability, allowing timely and personalized corrective strategies.

Personalized Nutrition Management: Participants received personalized dietary plans customized to metabolic profile, caloric needs, food preferences, and CGM-derived glycemic responses. Interventions targeted glycemic optimization via balanced macronutrient composition (40-45% carbohydrates, 25-30% protein, 25-30% fats), with modifications informed by insulin sensitivity and postprandial glucose variability. Plans emphasized portion control, low-glycemic index foods (GI <55), high dietary fiber intake (≥35 g/day), and reduced refined carbohydrates/ultra-processed foods.

Dietary data were continuously logged and analysed within the platform, enabling real-time feedback and iterative modification of meal plans based on observed glycemic responses and adherence patterns, thereby enhancing flexibility and long-term implementation. Nutrient timing strategies: early dinners, consistent lunch intervals, and macronutrient pairing (carbohydrates with proteins or healthy fats), were incorporated to promote glycemic stability and circadian alignment, with adjustments personalized to individual routines to improve sustainability.

Structured Physical Activity Guidance: Physical activity prescriptions were tailored to CGM-derived glucose profiles to optimize glycemic excursions and metabolic outcomes. Participants followed individualized plans incorporating daily aerobic exercises (brisk walking, cycling, or yoga) and resistance training 2-3 times weekly, targeting insulin sensitization and muscle mass preservation. Activity data were continuously tracked and integrated with glycemic responses, allowing refinement of exercise intensity, frequency, and timing based on individual metabolic outcomes, with periodic review during coaching interactions. This adaptive approach supported both sustained engagement and structured re-initiation after lapses, ensuring continuity of metabolic benefits.

Behavioral and Mental Wellness Interventions: Psychological well-being and behavioural challenges were routinely assessed to identify individuals requiring additional support. Participants with elevated levels of distress or behavioural difficulty were provided with structured, 60-minute one-on-one mental wellness sessions conducted by certified clinical psychologists, addressing diabetes-specific emotional distress, stress-induced behavioral dysregulation, reduced motivation, and coping strategies related to diabetes management.

Evidence-based therapeutic approaches, including cognitive behavioral therapy, mindfulness-based stress reduction, and guided relaxation techniques, were employed to improve psychological resilience and behavioral regulation. Additionally, diaphragmatic breathing exercises and structured sleep hygiene protocols were introduced to enhance overall mental well-being and support glycemic regulation. All participants received continuous behavioral coaching through the SugarFit mobile platform, which facilitated structured tracking of lifestyle metrics, access to educational content, asynchronous communication, and on-demand consultations. Health coaches maintained regular interactions to monitor engagement, reassess behavioral goals, and deliver personalized feedback aimed at reinforcing adherence.

These interactions were supported by a closed-loop feedback mechanism, wherein real-time inputs from CGM and lifestyle tracking were continuously evaluated to guide both immediate and longitudinal adjustments in intervention strategies. Behavioural nudges, coach-led feedback, and clinician oversight functioned synergistically to reinforce adherence, address deviations, and sustain engagement. This enabled timely intervention during periods of glycemic instability or reduced compliance, thereby minimizing the risk of sustained deterioration.

Participants were systematically educated on the clinical importance of sustained lifestyle modification, including its role in maintaining glycemic stability, preventing relapse following periods of disengagement, and supporting long-term metabolic health. This education emphasized the relationship between consistent behavioral adherence and durable clinical outcomes, thereby strengthening patient awareness, motivation, and self-management capacity.

This feedback-driven approach further supported both maintenance and recovery pathways, wherein continuous engagement reinforced effective behaviours and stabilized metabolic improvements, while periods of re-engagement enabled recalibration of interventions and recovery of glycemic control.

Comparison (C): Comparative analysis was performed between participants with continuous engagement (Cohort 1) and those with intermittent engagement and re-initiation (Cohort 2), to evaluate differences in sustainability and recovery of clinical outcomes.

Outcomes (O): The primary outcomes were longitudinal changes in glycemic parameters (HbA1c and FBS) and anthropometric measures (body weight). These outcomes were assessed at multiple timepoints across the study duration to evaluate both short-term improvements and long-term sustainability.

Time (T): Outcomes were evaluated over a longitudinal follow-up period of up to 36 months (3 years), with assessments conducted at baseline and predefined intervals. Participants in Cohort 1 (continuous engagement) remained actively engaged throughout the study period, with follow-up visits at 12 months (year 1), 24 months (year 2), and 36 months (year 3), enabling evaluation of sustained clinical outcomes under uninterrupted participation. In contrast, Cohort 2 (intermittent engagement) followed a phased trajectory consisting of an initial 12-month period of active participation (year 1), followed by a discontinuation phase during year 2 (months 13-24; approximately 300-600 days), and subsequent re-initiation with follow-up extending to 36 months (year 3). This unified temporal framework allowed assessment of sustained improvement in Cohort 1, deterioration during disengagement in Cohort 2, and the extent of clinical recovery following re-engagement.

Data Collection and Variables

Demographic and clinical data, including age, sex, duration of diabetes, HbA1c, FBS, and body weight, were extracted from program records at baseline and at predefined follow-up intervals corresponding to participation, discontinuation, and re-initiation phases. For Cohort 2, these intervals explicitly captured data during the discontinuation phase and after re-initiation, while Cohort 1 was assessed at equivalent timepoints under continuous engagement.

Statistical Analysis

Continuous variables were expressed as mean ± standard deviation. Longitudinal changes within cohorts were assessed using non-parametric repeated measures analysis (Friedman test), followed by pairwise comparisons using the Wilcoxon signed-rank test where applicable. Comparative analyses between cohorts were performed to evaluate differences in outcome trajectories. A p-value of <0.05 was considered statistically significant.

Ethical Considerations

As a retrospective analysis of anonymized program data, the study adhered to ethical standards for observational research. Participant confidentiality and data privacy were maintained throughout the analysis.

RESULTS

A total of 785 individuals with T2D were included and stratified into two cohorts based on engagement patterns: Cohort 1 (continuous engagement; n = 405) and Cohort 2 (intermittent engagement with re-initiation; n = 380). The mean age of participants was comparable between cohorts 52.7 ± 11.1 vs 51.91 ± 10.91 years, with a higher proportion of males in both groups (Cohort 1: 281/124; Cohort 2: 292/88, male/female). The mean duration of diabetes was similar 10.9

± 7.7 vs 11.2 ± 7.6 years, indicating a relatively homogeneous population with long-standing disease at baseline. Anthropometric characteristics were also comparable, including mean height 166.7 ± 8.9 cm vs 168.4 ± 8.60 cm).

Table 1: Demographic characteristics of study participants

Parameters	Cohort 1	Cohort 2
Sample size (n)	405	380
Age (Years)	52.7 ± 11.1	51.91 ± 10.91
Gender (Male/Female; n)	281/124 (Male/Female)	292/88 (Male/Female)
Duration of diabetes (Years)	10.9 ± 7.7	11.2 ± 7.6
Height (cm)	166.7 ± 8.9	168.4 ± 8.60

Cohort 1: Longitudinal Glycemic and Anthropometric Outcomes Under Continuous Engagement

A total of 405 participants with continuous engagement were analyzed over a 3-year follow-up period. Descriptive statistics (**Table 2**) demonstrated marked improvements across glycemic and anthropometric parameters from baseline through subsequent time points, which were further substantiated by both overall and pairwise statistical analyses (Tables 3 and 4).

At baseline, participants exhibited poor glycemic control, with a mean HbA1c of 10.53 ± 1.57%. Following program initiation, a substantial reduction was observed by Year 1 (7.29 ± 1.18%), which was maintained through Year 2 (7.2 ± 1.13%) and Year 3 (7.2 ± 1.11%), indicating sustained glycemic stability with minimal variability across time points (Table 2). Consistent with these descriptive trends, inferential analysis confirmed the robustness of HbA1c improvement. The overall reduction in HbA1c across all timepoints was highly significant, as demonstrated by the Friedman test ($p < 0.05$, Kendall's $W = 0.61$), indicating a strong effect size (Table 3). Pairwise comparisons confirmed that reductions from baseline were sustained and statistically significant at all follow-up intervals (Wilcoxon signed-rank test: Baseline vs Year 1, $\Delta = -3.488$; Baseline vs Year 2, $\Delta = -3.582$; Baseline vs Year 3, $\Delta = -3.573$; all $p < 0.05$, Bonferroni corrected) (Table 4).

A similar but more gradual pattern was observed for fasting blood sugar (FBS). At baseline, the mean FBS was 144.02 ± 39.07 mg/dL, which declined to 138.17 ± 43.02 mg/dL at Year 1. This downward trajectory continued through Year 2 (130.85 ± 33.65 mg/dL) and Year 3 (129.19 ± 29.35 mg/dL), indicating progressive improvement in fasting glycemic levels (Table 2). While the magnitude of change was comparatively modest, statistical testing confirmed its significance. The overall longitudinal trend was significant (Friedman test: $p < 0.05$, Kendall's $W = 0.03$), although the effect size remained small (Table 3). Pairwise analyses further clarified this pattern, showing that early reductions were modest but statistically significant (Baseline vs Year 1, $\Delta = -6.153$; $p < 0.05$), whereas more pronounced and sustained reductions were evident over longer durations (Baseline vs Year 2, $\Delta = -13.304$; Baseline vs Year 3, $\Delta = -14.848$; both $p < 0.05$, Bonferroni corrected) (Table 4).

Turning to anthropometric outcomes, body weight demonstrated a consistent downward trend, decreasing from a baseline mean of 75.09 ± 14.10 kg to 72.54 ± 12.73 kg at Year 1. This reduction was sustained at Year 2 (72.88 ± 13.20 kg) and further improved at Year 3 (72.20 ± 12.69 kg), indicating maintenance of weight loss over time (Table 2). These trends were supported by statistically significant findings. The overall longitudinal change was statistically significant (Friedman test: $p < 0.05$, Kendall's $W = 0.16$), reflecting a small-to-moderate effect size (Table 3). Pairwise analyses demonstrated consistent reductions from baseline across all timepoints (Wilcoxon signed-rank test: Baseline vs Year 1, $\Delta = -2.458$; Baseline vs Year 2, $\Delta = -2.209$; Baseline vs Year 3, $\Delta = -2.881$; all $p < 0.05$, Bonferroni corrected) (Table 4).

Table 2: Descriptive Statistics of Glycemic and Anthropometric Parameters Across Timepoints in Cohort 1 (Continuous Engagement; N=405)

Parameter	Timepoint	Mean	SD
HbA1c (%)	Baseline	10.53	1.18
	Avg Year 1	7.29	1.18
	Avg Year 2	7.2	1.13
	Avg Year 3	7.2	1.11
Weight (Kg)	Baseline	75.09	14.10
	Avg Year 1	72.54	12.73
	Avg Year 2	72.88	13.20
	Avg Year 3	72.20	12.69
FBS (mg/dL)	Baseline	144.02	39.07
	Avg Year 1	138.17	43.02
	Avg Year 2	130.85	33.65
	Avg Year 3	129.19	29.35

Table 3. Overall Longitudinal Changes in Glycemic and Anthropometric Parameters in Cohort 1 (Friedman Test)

Parameter	p-value	Kendall's W (effect size)
HbA1c	<0.05	0.6132
Weight	<0.05	0.1556
FBS	<0.05	0.0279
Notes: Effect size r: 0.1=small, 0.3=medium, 0.5=large (**Kendall's W**)		

Table 4. Pairwise Comparisons of Glycemic and Anthropometric Parameters Across Timepoints in Cohort 1 (Wilcoxon Signed-Rank Test with Bonferroni Correction)

Parameter	Comparison	Mean difference	p-value (Bonferroni)
HbA1c (%)	Baseline vs Year 1	-3.488	< 0.05
	Baseline vs Year 2	-3.582	< 0.05
	Baseline vs Year 3	-3.573	< 0.05
Weight (Kg)	Baseline vs Year 1	-2.458	< 0.05
	Baseline vs Year 2	-2.209	< 0.05
	Baseline vs Year 3	-2.881	< 0.05
FBS (mg/dL)	Baseline vs Year 1	-6.153	< 0.05
	Baseline vs Year 2	-13.304	< 0.05
	Baseline vs Year 3	-14.848	< 0.05

Taken together, these findings highlight a coherent pattern of improvement across all evaluated parameters. Continuous engagement in the program was associated with statistically significant and clinically meaningful reductions in HbA1c, FBS, and body weight, as evidenced by both descriptive and inferential analyses. Notably, HbA1c exhibited the most pronounced and sustained improvement, supported by a large effect size, indicating robust long-term glycemic control. In contrast, weight reduction, while moderate in magnitude, remained consistently maintained, underscoring the role of sustained lifestyle modification. FBS, on the other hand, demonstrated a more gradual improvement trajectory with a smaller effect size, likely reflecting its inherent biological variability and sensitivity to short-term behavioral fluctuations.

Overall, the convergence of findings from descriptive statistics, the Friedman test, and the Wilcoxon pairwise comparisons provides strong evidence that continuous engagement facilitates both metabolic improvement and long-term stability. Importantly, no evidence of regression was observed across the 3-year follow-up period, reinforcing the critical role of sustained participation in achieving durable outcomes in real-world diabetes management.

Cohort 2: Longitudinal Glycemic and Anthropometric Outcomes Under Intermittent Engagement and Re-initiation

A total of 380 participants with intermittent engagement patterns were analyzed, characterized by an initial phase of participation, followed by discontinuation, and subsequent re-initiation. This cohort provides critical insight into the dynamic nature of real-world adherence and its impact on metabolic outcomes. Descriptive trends (Table 5), along with overall and pairwise statistical analyses (Tables 6 and 7), collectively illustrate a distinct trajectory of initial improvement, subsequent deterioration, and clinically meaningful recovery following re-engagement. At baseline, participants exhibited moderately elevated HbA1c levels, with a mean of 8.83 ± 1.76%, indicating suboptimal glycemic control. Following initial engagement, a clinically meaningful reduction was observed at Year 1 (7.43 ± 1.35%), demonstrating effective early response to intervention. However, this improvement was not sustained during the discontinuation phase, with HbA1c increasing to 8.29 ± 1.81%, reflecting a reversal of previously achieved metabolic benefits. Upon re-initiation, HbA1c again declined to 7.61 ± 1.31%, indicating restoration of glycemic control, although not fully returning to Year 1 levels (Table 5). These observations were supported by statistically significant findings. The overall change across baseline, Year 1, and discontinuation phases was significant (Friedman test: $p < 0.05$, Kendall's $W = 0.2822$), indicating a moderate effect size (Table 6). Pairwise comparisons confirmed a significant reduction during initial engagement (Baseline vs Year 1 $\Delta = -1.4$; $p < 0.05$), followed by significant deterioration during discontinuation (Baseline vs Discontinuation $\Delta = -0.535$; $p < 0.05$). Importantly, re-initiation was

associated with a significant improvement (Discontinuation vs Post re-initiation Δ = -0.761; p < 0.05), reinforcing the reversibility of glycemic deterioration with renewed intervention (Table 7).

A comparable but more variable trend was observed for fasting blood sugar (FBS). At baseline, the mean FBS was 137.32 ± 38.50 mg/dL, with minimal change at Year 1 (135.85 ± 35.74 mg/dL), indicating a relatively modest early response. However, a marked increase was observed during discontinuation, with FBS rising to 150.14 ± 49.70 mg/dL, suggesting deterioration in glycemic control. Following re-initiation, FBS declined to 142.87 ± 43.96 mg/dL, indicating partial recovery, although levels remained higher compared to initial improvement (Table 5). The overall trend was statistically significant (Friedman test: p < 0.05, Kendall's W = 0.0238), albeit with a small effect size (Table 6). Pairwise comparisons indicated that early changes were not statistically significant (Baseline vs Year 1 Δ = −0.525; p > 0.05), whereas discontinuation was associated with a significant increase (Baseline vs Discontinuation Δ = +12.781; p < 0.05). In contrast, the reduction following re-initiation did not reach statistical significance (Discontinuation vs Post re-initiation Δ = −6.446; p > 0.05), suggesting incomplete restoration of fasting glycemic control (Table 7).

Body weight demonstrated a pattern consistent with engagement dynamics. At baseline, the mean weight was 76.18 ± 14.73 kg, which decreased to 74.46 ± 14.51 kg at Year 1, indicating an effective initial response. During discontinuation, weight showed a slight increase to 74.51 ± 15.15 kg, reflecting loss of adherence. Following re-initiation, weight further decreased to 72.77 ± 12.63 kg, indicating recovery and additional improvement beyond initial levels (Table 5). These changes were statistically significant overall (Friedman test: p < 0.05, Kendall's W = 0.09), reflecting a small effect size (Table 6). Pairwise comparisons demonstrated significant reductions during initial engagement (Baseline vs Year 1, Δ = −1.418; p < 0.05), a modest but significant increase during discontinuation (Baseline vs Discontinuation, Δ = −0.752; p < 0.05), and a significant reduction following re-initiation (Discontinuation vs Post re-initiation, Δ = −1.525; p < 0.05) (Table 7).

Table 5. Descriptive Statistics of Glycemic and Anthropometric Parameters Across Timepoints in Cohort 2 (Intermittent Engagement and Re-initiation; N=380)

Parameter	Timepoint	Mean	SD
HbA1c (%)	Baseline	8.83	1.76
	Avg Year 1	7.43	1.35
	Discontinuation	8.29	1.81
	Post re-initiation	7.61	1.31
Weight (Kg)	Baseline	76.18	14.73
	Avg Year 1	74.46	14.51
	Discontinuation	74.51	15.15
	Post re-initiation	72.77	12.63
FBS (mg/dL)	Baseline	137.32	38.50
	Avg Year 1	135.85	35.74
	Discontinuation	150.14	49.70
	Post re-initiation	142.87	43.96

Table 6. Overall Longitudinal Changes in Glycemic and Anthropometric Parameters in Cohort 2 (Friedman Test)

Parameter	p-value	Kendall's W (effect size)
HbA1c	< 0.05	0.2822
Weight	< 0.05	0.0923
FBS	< 0.05	0.0238

Table 7. Pairwise Comparisons of Glycemic and Anthropometric Parameters Across Engagement Phases in Cohort 2 (Wilcoxon Signed-Rank Test with Bonferroni Correction)

Parameter	Comparison	Mean difference	p-value (Bonferroni)
HbA1c (%)	Baseline vs Year 1	-1.4	< 0.05
	Baseline vs Discontinuation	-0.535	< 0.05
	Discontinuation vs post re-initiation	-0.761	< 0.05
Weight (Kg)	Baseline vs Year 1	-1.418	< 0.05
	Baseline vs Discontinuation	-0.752	< 0.05
	Discontinuation vs post re-initiation	-1.525	< 0.05
FBS (mg/dL)	Baseline vs Year 1	-0.525	> 0.05
	Baseline vs Discontinuation	12.781	< 0.05
	Discontinuation vs post re-initiation	-6.446	> 0.05

Notes: Negative represents Reduction

Across all evaluated parameters, intermittent engagement was associated with a fluctuating trajectory of metabolic control, characterized by initial improvement, regression during discontinuation, and partial recovery upon re-initiation. HbA1c demonstrated a moderate effect size with clear reversibility, while weight changes were smaller but consistently responsive to engagement status. In contrast, FBS exhibited greater variability and incomplete recovery, reflecting its sensitivity to short-term behavioral and physiological fluctuations. Overall, the integration of descriptive statistics with Friedman and Wilcoxon analyses indicates that although discontinuation leads to deterioration in clinical outcomes, these effects are not irreversible. Re-engagement enables meaningful restoration of metabolic control, underscoring the importance of sustained or renewed participation in achieving long-term outcomes in real-world diabetes management.

DISCUSSION

The present study provides comprehensive real-world evidence on the long-term metabolic consequences of continuous versus intermittent engagement in a structured, technology-enabled lifestyle intervention among individuals with T2D. Over a period of 3 years, we identified two clinically distinct behavioral and glycemic trajectories: a sustained, durable improvement associated with uninterrupted engagement, and a pattern of initial benefit followed by deterioration after disengagement and clinically meaningful improvements upon re-engagement. These findings reinforce foundational principles in diabetes care, that while structured lifestyle programs can induce early metabolic improvement, long-term effectiveness is fundamentally dependent on sustained behavioral adherence and ongoing therapeutic support [14,15].

The present study extends prior evidence by demonstrating that durable glycemic outcomes require not only adherence, but continuous, adaptive support systems capable of guiding individuals through the evolving behavioral and psychosocial demands of chronic diabetes self-management [16-18]. Participants with uninterrupted engagement (Cohort 1) exhibited robust and clinically meaningful reductions in HbA1c that were maintained across the entire 3-year period. Prior digital diabetes interventions have shown that persistent participation correlates with improved glycemic outcomes [19], yet most earlier studies have assessed engagement within shorter time horizons. In contrast, our extended follow-up provides evidence of a transition from early metabolic correction to long-term glycemic stabilization, a stage that is often difficult to achieve in routine clinical practice but has been reported in structured precision-based models [19,20]. These findings underscore the capacity of sustained, data-driven engagement to maintain glycemic improvements well beyond the initial intensive intervention phase. Parallel improvements in FBS and body weight highlight the broader metabolic benefits of uninterrupted participation. Although changes in FBS were modest, reflecting its sensitivity to short-term behavioral fluctuations, weight reduction was sustained, indicating the cumulative effect of long-term adherence to dietary and physical activity modifications. These findings are aligned with long-term lifestyle intervention trials demonstrating persistent weight reduction and improved metabolic profiles over extended follow-up [21-23]. However, unlike prior studies conducted in controlled research environments, the present study demonstrates comparable durability within a real-world, technology-enabled care model, thereby enhancing the translational relevance of these outcomes.

This observed durability can be plausibly attributed to the integrated, multimodal design of the intervention implemented in Cohort 1, which integrates CGM, personalized nutrition planning, structured physical activity, and real-time behavioral coaching. Prior evidence indicates that interventions incorporating continuous monitoring, individualized feedback, and ongoing support are associated with superior glycemic outcomes and enhanced self-management behaviors [24-26].

Such an approach is particularly relevant given the inherently complex and behaviorally demanding nature of diabetes management, which requires ongoing decision-making related to medication use, dietary

intake, physical activity, and glucose monitoring. These continuous demands impose a sustained behavioral burden and are closely associated with diabetes distress [27]. Consequently, care models that incorporate routine assessment of psychosocial and behavioral factors are essential to support sustained engagement and prevent distress-related disengagement [28,29]. Within this context, the sustained metabolic improvements observed in Cohort 1 likely reflect the program's ability to provide continuous, adaptive support across both behavioral and emotional domains, thereby facilitating long-term adherence and outcome stability.

In contrast, the trajectory observed in Cohort 2 highlights the clinical vulnerability of early metabolic improvements when sustained engagement is disrupted. This cohort demonstrated substantial initial improvements followed by deterioration during periods of disengagement, with only partial restoration after re-engagement.

Previous studies have reported the progressive attenuation of lifestyle-induced metabolic benefits in the absence of structured long-term support [14,15]; however, limited evidence has directly characterized the real-world metabolic impact of disengagement followed by re-entry into care. In this regard, the present study extends existing literature by quantifying the magnitude of metabolic relapse and demonstrating that although re-engagement yields meaningful improvement, it does not fully restore the level of glycemic control achieved during uninterrupted participation.

The reduced sustainability observed in Cohort 2 is likely driven by disruptions across core domains of diabetes self-management, including dietary regulation, physical activity, glucose monitoring, medication adherence, problem-solving, risk mitigation, and emotional coping, collectively essential for long-term glycemic control [29]. In addition, psychosocial factors such as diminished behavioural motivation and increased diabetes distress may further exacerbate disengagement and contribute to metabolic deterioration [30]. Evidence from the U-TURN trial similarly demonstrates that while intensive lifestyle interventions can produce early clinical benefits, their durability is contingent upon sustained, structured support systems [31]. Consistent with these findings, the present study provides real-world evidence of the metabolic consequences of interrupted engagement and highlights the limited but clinically meaningful reversibility of disengagement-related deterioration following re-initiation of care.

A key mechanism underlying both sustained improvement and successful recovery appears to be continuous, bidirectional communication between participants and healthcare or coaching teams. Technology-enabled interventions are most effective when they incorporate individualized feedback, patient-generated data, structured education, and continuous interaction [32,33]. These dynamic feedback loops act as reinforcement systems that promote self-regulation and durable engagement [34]. Given the persistent behavioral demands of diabetes, reinforcement strategies, including timely feedback and reward-based mechanisms, are essential for habit formation and long-term behavioral persistence. This interpretation aligns with social cognitive and self-determination theories emphasizing self-efficacy, autonomy, competence, and relatedness as core determinants of sustained behavior change [35,36].

While the intention-behavior gap has traditionally explained the disconnect between motivation and action, the present study suggests that a more clinically relevant barrier is the challenge of maintaining behavior after initial adoption. We propose the concept of a "behavior-sustainability gap" to characterize this difficulty. Evidence of declining effectiveness in digital interventions as engagement wanes supports this conceptualization [25,26], emphasizing that long-term health outcomes depend critically on sustained participation [37].

Within this framework, maintaining engagement emerges as a central determinant of therapeutic success in diabetes care. Clinician-supported and coach-led models further reinforce this pathway by strengthening adherence through regular follow-up, structured counseling, and continuous interaction, all of which have been shown to improve clinical outcomes [38]. In addition, health coaching, through its individualized, adaptive, and patient-centered approach, facilitates sustained behavioral change over time. Beyond formal healthcare delivery systems, broader support ecosystems, including family involvement, social networks, and digital community environments, also play a meaningful role in enhancing adherence and improving metabolic outcomes [39]. Conversely, psychological factors such as depression and diabetes distress are consistently associated with reduced adherence, underscoring the importance of integrating behavioral and emotional support within chronic disease management frameworks. Collectively, these observations position sustained engagement not merely as a supportive component but as a core therapeutic mechanism in diabetes management. Real-world effectiveness is therefore strongly modulated by engagement intensity, with higher levels of sustained participation consistently associated with superior metabolic and behavioral outcomes [30,37].

This study has several strengths, including its large sample size, extended 3-year follow-up duration, and real-world design, all of which enhance external validity and generalizability. However, certain limitations should be acknowledged. However, the retrospective design, particularly in the context of a large cohort with multiple, time-varying parameters, could introduce the possibility of selection bias, and the absence of a usual-care or untreated control group limits causal inference, highlighting the need for future prospective studies, with more diverse populations, and comprehensive behavioral, psychosocial, and possible pharmacological assessments to further validate and extend these findings.

Overall, the present findings demonstrate that sustained engagement in a structured, technology-enabled diabetes management program is associated with durable improvements in glycemic control, weight, and overall metabolic health over three years, whereas intermittent engagement is associated with metabolic deterioration and only clinically meaningful restoration following re-engagement. These contrasting trajectories underscore the clinical importance of maintaining long-term participation rather than relying on episodic adherence. Collectively, these results highlight that durable diabetes control is dependent not only on initiating lifestyle modification but on maintaining it through continuous, adaptive, and patient-centered support systems that reinforce self-management behaviors over time.

Overall, sustained continuous engagement in a structured, technology-enabled diabetes management program is associated with sustained and clinically meaningful improvements in glycemic control, weight, and overall metabolic health over three years. In contrast, intermittent engagement results in metabolic regression and only partial recovery upon re-engagement, highlighting both the reversibility of lifestyle-induced benefits and the limitations of episodic adherence. These findings underscore the importance of long-term, adaptive, and patient-centered support systems as essential components of effective diabetes management models and provide compelling real-world evidence that sustained engagement is a critical determinant of durable clinical outcomes in T2D.

CONCLUSION

Our findings indicate that sustained metabolic control in T2D relies primarily on the long-term continuation of behavioral interventions rather than their initial adoption in real-world settings. While motivation and initial behaviour change are important, our findings highlight the critical role of addressing the behaviour-sustainability gap, as demonstrated by the contrasting trajectories of continuous versus intermittent engagement, where early improvements are often not maintained without ongoing support. Participants with continuous engagement achieved durable glycemic and metabolic stability, whereas those with interrupted engagement experienced regression followed by only partial recovery upon re-engagement, underscoring both the reversibility of benefits and the limitations of episodic participation.

In this context, continuous engagement through structured, technology-enabled, and personalized support systems, such as those implemented in the SugarFit program, plays a pivotal role in bridging this gap by supporting sustained self-management behaviors through ongoing feedback, behavioral reinforcement, and adaptive guidance. In contrast, discontinuation of support is associated with deterioration in both behavioural and metabolic outcomes, reflecting the inherently dynamic and non-self-sustaining nature of diabetes self-management. These findings emphasize that long-term, patient-centered, and interactive care models are essential for effective diabetes management in real-world settings. Importantly, such models extend beyond behaviour initiation and instead focus on maintaining behavioural consistency through continuous monitoring, bidirectional communication, and personalized intervention strategies. Overall, our findings suggest that sustainable diabetes control is achieved when

externally supported behaviours are progressively internalized into stable daily routines, highlighting the need for care models that facilitate this transition from external guidance to internal self-regulation.

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