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Glucometric parameter changes in patients with type 2 diabetes during ramadan fasting: A prospective comparative real-world study

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ABSTRACT

Background: This study assessed glucometric changes in Type 2 diabetes mellitus (T2DM) patients before, during, and after Ramadan fasting using an intermittently scanned continuous glucose monitoring system (isCGMS).
Methods: This prospective comparative study included T2DM patients aged 30–70 years who were receiving nonintensive insulin in Riyadh, Saudi Arabia. In addition to the baseline characteristics, glycated hemoglobin (HbA1c) and ambulatory glucose profile (AGP)-derived metric data were collected at three specific points: pre-, during-, and post-Ramadan. Self-care activities during Ramadan were evaluated using the Diabetes Self-Management Questionnaire (DSMQ).
Results: Overall, a total of 93 T2DM patients were enrolled in the study. Their mean age ±SD age was 47.9 ± 7.5 years, and 51.6 % of them were males. Compared with pre- and post-Ramadan, there was a significant decrease in HbA1c ($p < 0.001$ for both periods), average glucose level ($p = 0.001$ and $p = 0.026$, respectively), glucose variability ($p = 0.043$ and $p = 0.005$, respectively), and % time above the range of 181–250 mg/dL ($p < 0.001$ for both periods), as well as a significant increase in % time in target (70–180 mg/dL) during Ramadan ($p < 0.001$ for both periods). However, the % time below 54 mg/dL was slightly greater during Ramadan than both pre- and post-Ramadan ($p < 0.001$ and $p = 0.002$, respectively). Furthermore, 32.3 % reported inadequate self-care behaviors during Ramadan.
Conclusions: Ramadan fasting could improve glucose levels in T2DM patients who were not on intensive insulin, with a relatively low incidence of hypoglycemia.

1. Introduction

Ramadan, the ninth month of the Islamic lunar calendar, is the holy month of fasting [1]. Fasting during Ramadan is an obligatory practice carried out by adult Muslims worldwide. It involves abstaining from eating, drinking, smoking, and oral medication from predawn to sunset for one month every lunar calendar year. The duration of Ramadan fasting ranges from 10 to 19 h, depending on geographical and seasonal conditions [2].

Recent global estimates suggest that more than 148 million Muslims are diagnosed with diabetes. Although patients suffering from chronic illnesses, including diabetes, are exempted from fasting according to the Quran, healthcare, and religious authorities, approximately 116 million choose to fast [3,4]. A population-based epidemiology of diabetes and Ramadan study conducted among 12,243 people in 13 Islamic countries revealed that approximately 79 % of Muslims with type 2 diabetes (T2DM) fast during Ramadan [1].

Diabetes mellitus is reaching epidemic proportions globally, leading to public and personal burdens, as well as mortality and morbidity in many developed and developing countries [1,5–9]. Ramadan fasting could lead to medical challenges for patients with diabetes and their healthcare providers due to changes in physical activity, diet, mealtimes, sleep, and medication frequency [2,10]. During Ramadan, Muslims consume meals only before dawn and after sunset, leading to changes in their meal schedule. This alteration in eating patterns can affect sleep habits, daily routines, and diabetes complications [11–15]. In addition, the medication schedule during the daytime of Ramadan is changed because of fasting, which may affect glucose levels in diabetes patients [1,12].

It has also been shown that fasting for long periods can increase the risk of hypoglycemia, hyperglycemia, diabetic ketoacidosis, dehydration, and thrombosis caused by increases in several hormones, including adrenaline, noradrenaline, and cortisol, among patients with type 2 diabetes mellitus (T2DM) [1,16]. An increase in glycemic variability

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with fasting during Ramadan has also been reported, which was linked to the development of acute and chronic complications [17,18].

However, several studies revealed that fasting may be beneficial and associated with a slight improvement in the metabolic profile and anthropometric measurement of T2DM, as measured by glycated hemoglobin (HbA1c), fasting blood glucose, cholesterol, body weight, and waist circumference [5,19–21].

Continuous glucose monitoring (CGM) technologies, including real-time CGM (rtCGM) and intermittently scanned continuous glucose monitoring (isCGM), also known as flash glucose monitoring (FGM), enable continuous and real-time glucose monitoring throughout the day. The isCGM was found to be safe and associated with improved glycemic control and reduced hypoglycemic events among T2DM patients on basal insulin or noninsulin therapy [22,23].

The present study aimed to assess glycemic change based on HbA1c and ambulatory glucose profile (AGP)-derived metrics as defined by the International Consensus using a second-generation isCGM (Freestyle Libre 2) in T2DM patients not treated with an intensive insulin regimen for three months: one month before Ramadan, one month after Ramadan, and one month after Ramadan in Saudi Arabia.

2. Materials and methods

2.1. Study design

This is a prospective comparative study conducted in a tertiary diabetes treatment center in Prince Sultan Military Medical City (PSMMC), Riyadh, Saudi Arabia, during three specific periods: one month before (prior to), during, and one month after Ramadan, 2023. The duration of Ramadan was 30 days, from March 22nd to April 20th, 2023, with an average fasting duration of 13 h and 29 min.

The research was performed according to the guidelines of the Declaration of Helsinki and approved by the Research and Ethics Committee of PSMMC, Riyadh, Saudi Arabia (IRB# # 1394).

2.2. Study participants

The study included T2DM patients aged 30–70 years treated with nonintensive insulin regimens who were willing and capable of Ramadan fasting during 2023 without any major contraindications according to the new IDF-DAR risk stratification tool [24] and who continuously utilized isCGM (FreeStyle Libre 2 with real-time alarms) for self-monitoring of their glucose level for at least three months before enrollment in the study.

The exclusion criteria included patients with unstable or uncontrolled diabetes, those with a high probability of switching to intensive insulin regimens during Ramadan, and those at very high risk for fasting based on the Diabetes And Ramadan (DAR) guidelines [24]. Additionally, patients who were unwilling to continue the study, who had a time sensor active <70 %, or who had planned/scheduled surgeries during Ramadan were excluded from the study.

Prior to Ramadan, a structural therapeutic educational program was provided to the participants. The program aimed to guide the participants on appropriate diet, exercise, and meal schedules, as well as the intake of antidiabetic medications during Ramadan. The programme also included instructions on when a patient can fast due to hyper or hypo-glycemia in compliance with the DAR guidelines [24].

2.3. Data collection and study outcomes

2.3.1. Baseline characteristics of patients

At baseline, demographic data, including age, sex, and BMI, as well as clinical characteristics such as medical history, diabetes duration, and treatment of the participants, were collected.

2.3.2. Glycemic control measures

Glucometric parameters for one month before, during, and after Ramadan included HbA1c, average glucose (mg/dL), glucose variability (GV), glucose monitoring indicator (GMI %), time spent in the target (TIR) range (70–180 mg/dL), %, time spent below the target (TBR) range <70 mg/dL or <54 mg/dL, %, time spent above the target (TAR) range 1: (181–250 : (181–250 he target (TAR) range <70 mg/dL or <54 mg/dL, and the number of reported hypoglycemic events (low glucose events (episodes/28 days)) were reported. These data were available to be viewed, collected, and examined by the authors via the LibreView platform.

2.3.3. Diabetes self-management questionnaire (DSMQ)

The diabetes self-management activities of the patients were measured during Ramadan using the validated Arabic version of the Diabetes Self-Management Questionnaire (DSMQ) [25]permissions granted in licensing agreements. The questionnaire is composed of four subscales with 16 items: "Glucose Management," "Dietary Control," "Physical Activity," and "Health-Care Use." The final item (item 16) asks respondents to rate their overall diabetes self-care, and its score is included only in the "sum scale."

The DSMQ score consists of adding the scores of all items after reversing the scores of nine negatively keyed statements. The scale scores are then transformed to a scale from 0 to 10, where a score of 10 represents the most effective self-care behavior.

2.3.4. Statistical analysis

The statistical analysis was performed using IBM SPSS 25.0 (Statistical Package for the Social Science). Frequencies (number of cases) and valid percentages were used for categorical variables. Continuous variables are presented as the mean (SD) or median (IQR). The Shapiro–Wilk test was used to determine the normality of the parameter distribution. A paired *t*-test or Wilcoxon signed-rank test was used to compare HbA1c and AGP-derived metrics before, during, and after Ramadan. Pearson correlation or Spearman correlation tests were used to assess the correlation between the DSMQ sum scale and its four subscales with HBA1c and AGP metrics during Ramadan. Pearson correlation test was used to assess the correlation between the DSMQ sum scale and HBA1c during ramadan among males, females, younger and older patients. A P value less than 0.05 was considered to indicate statistical significance.

3. Results

3.1. Baseline characteristics of the study population

Out of the 103 T2DM patients included in the study, 10 ineligible patients were excluded (Fig. 1). Overall, a total of 93 T2DM patients were enrolled in the study. Approximately half of the patients were male (51.6 %). The subjects had a mean ± SD age of 47.9 ± 7.5 years, a mean body mass index (BMI) of 29.7 ± 3.5 kg/m^2, and a mean diabetes duration of 7.1 ± 4.7 years. Dyslipidemia was the most common condition among the enrolled patients (46.2 %), followed by hypertension (34.4 %).

Various pharmacotherapies have been used for diabetes treatment, including sulfonylureas, dipeptidyl peptidase-4 (DPP4) inhibitors, thiazolidinediones, biguanides, basal insulin, premixed insulin analogs, and glucagon-like peptide-1 (GLP-1) agonists. Overall, 84 (90.3 %) of the patients were on Biguanides. In addition, nearly half of the patients received dipeptidyl peptidase-4 (DPP4) inhibitors (47.3 %), basal insulin (47.3 %), and glucagon-like peptide-1 (GLP-1) agonists (45.2 %). A total of 6.5 % of patients reported that they stopped fasting for one day due to glycemic issues. However, none of them experienced any glycemic issues requiring hospital or emergency visits during Ramadan (Table 1).

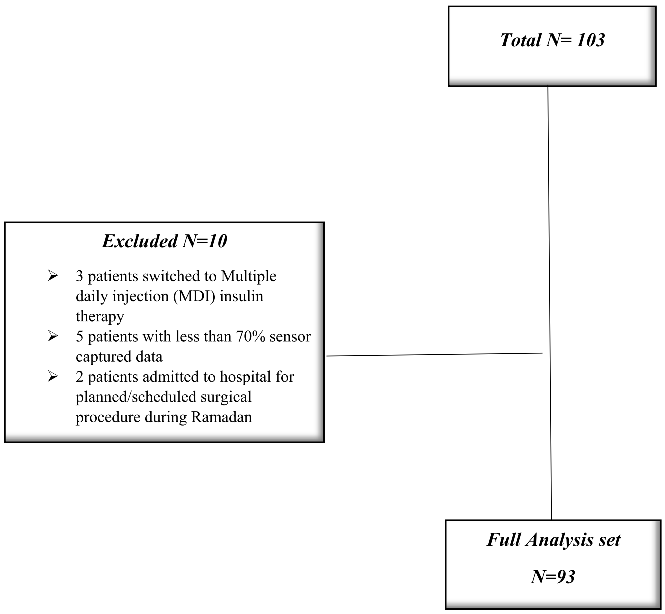

Fig. 1. Patient Disposition in the study.

3.2. Diabetes Self-Management Questionnaire (DSMQ) scores

Regarding the DSMQ, the median (IQR) total score was 6.2 (0.7) out of 10. The lowest score among the four subscales of the DSMQ was for physical activity, with a median (IQR) of 3.3 (1.1).

Moreover, the medians (IQRs) of the other subscales, glucose management, dietary control, and healthcare use, were 8.7 (0.6), 4.2 (1.7), and 5.6 (2.8), respectively (Table 1).

3.3. Glycemic control measures pre, during, and post ramadan

As indicated in Table 2, a significant decrease in HbA1c was detected during Ramadan compared with before Ramadan (7.9 vs. 8.2, $p < 0.001$) and after Ramadan (7.9 vs. 8.1, $p < 0.001$). The average glucose level (180.6 vs. 187.5; $p = 0.001$), GMI (7.9 vs. 8.0; $p < 0.001$), GV (32.8 vs. 34.9; $p = 0.043$), and TAR 181–250 mg/dL (23.9 vs. 30.0; $p < 0.001$) were significantly lower in the Ramadan group than in the Pre-Ramadan group. There was an increase in % Time in target (70–180 mg/dL) during Ramadan compared to pre-Ramadan (52.4 vs. 43.3; $p < 0.001$). Similarly, this was observed for the % TBR below 54 mg/dL (0.31 vs. 0.14; $p < 0.001$), and the % Time sensor was active (86.4 vs. 82.0; $p < 0.001$). On the other hand, TAR above 250 mg/dL, TBR below 70 mg/dL, and low glucose episodes were not significantly different before and during Ramadan ($p = 0.081$, 0.092, and 0.771, respectively) (see Table 3).

During and post-Ramadan, there was an improvement in the average glucose level (180.6 vs. 186; $p = 0.026$), GV (32.8 vs. 35.7; $p = 0.005$), percentage of time at 70–180 mg/dL (52.4 vs. 44.4; $p < 0.001$), and TAR (23.9 vs. 29.9; $p < 0.001$). However, there was a significant increase in the % TBR below 54 mg/dL and TAR above 250 mg/dL during Ramadan compared to post-Ramandn (0.31 vs. 0.16; $p = 0.002$ and 6.6 vs. 5.9; $p = 0.034$, respectively) (Fig. 2).

In addition, the present study demonstrated that there was no significant difference in low glucose events or TBR below 70 mg during or after Ramadan ($p = 0.058$ and 0.148, respectively).

A higher decrease in TAR (181–250 mg/dL) before/during Ramadan was observed among females compared to males (mean change: 7.93 ± 7.59 vs. −4.32 ± 5.97, $p = 0.012$, respectively). However, a higher increase was observed during/after Ramadan among females compared to males (mean change: 7.67 ± 7.98 vs. 4.27 ± 6.71, $p = 0.028$, respectively) (Table 4).

Table 1
Demographic and clinical characteristics of participants.

Demographic variables:		Total sample: n = 93 (100 %)
Age (years)[a]		47.9 ± 7.5
BMI (kg/m2)[a]		29.7 ± 3.5
Diabetes duration (years)[a]		7.1 ± 4.7
Gender[b]	Male	48 (51.6 %)
	Female	45 (48.4 %)
Medical history[b]		
Hypertension	Yes	32 (34.4 %)
	No	61 (65.6 %)
Dyslipidemia	Yes	43 (46.2 %)
	No	50 (53.8 %)
Retinopathy	Yes	16 (17.2 %)
	No	77 (82.8 %)
Nephropathy	Yes	4 (4.3 %)
	No	89 (95.7 %)
Neuropathy	Yes	5 (5.4 %)
	No	88 (94.6 %)
Stroke	Yes	3 (3.2 %)
	No	90 (96.8 %)
Coronary heart disease	Yes	10 (10.8 %)
	No	83 (89.2 %)
Amputation	Yes	2 (2.2 %)
	No	91 (97.8 %)
Foot ulcer	Yes	4 (4.3 %)
	No	89 (95.7 %)
Diabetes treatment[b]		
Sulphonylureas	Yes	27 (29 %)
	No	66 (71 %)
Dipeptidyl peptidase-4 (DPP4) inhibitors	Yes	44 (47.3 %)
	No	49 (52.7 %)
Thiazolidinedione	Yes	6 (6.5 %)
	No	87 (93.5 %)
Biguanides	Yes	84 (90.3 %)
	No	9 (9.7 %)
Basal insulin	Yes	44 (47.3 %)
	No	49 (52.7 %)
Premixed insulin analogs	Yes	11 (11.8 %)
	No	82 (88.2 %)
Glucagon-like peptide-1 (GLP-1) agonists	Yes	42(45.2 %)
	No	51 (54.8 %)
Glycemic issues during Ramadan [b]		
Hospital visits because of glycemic issues		0 (0 %)
Number of breaking fasting days (due to glycemic issues)	None	87 (93.5 %)
	1 day	6 (6.5 %)
Diabetes Self-Management Questionnaire (DSMQ) during Ramadan [c]		
Subscale 'Glucose Management		8.7 (0.6)
Subscale 'Dietary Control'		4.2 (1.7)
Subscale 'Physical Activity'		3.3 (1.1)
Subscale 'Health-Care Use'		5.6 (2.8)
DSMQ 'Sum Scale'		6.2 (0.7)

BMI: Body Mass Index.
[a] Numerical data are presented as the means ± standard deviations.
[b] Categorical data are presented as numbers (%).
[C] Numerical data, presented as the median (IQR).

3.4. Responses to the Diabetes Self-Management Questionnaire (DSMQ) among the participants

Table 4 shows the responses of T2DM patients regarding their self-management practices during Ramadan. Most of the participants checked and recorded their blood sugar levels with care (67.7 %); however, only a small proportion of them performed physical activity to achieve the optimal blood sugar level (1.1 %).

Furthermore, 32.3 % of the participants reported inadequate self-care behaviors during Ramadan. In addition, 90.3 %, 96.8 %, and 51.6 % of the patients had inadequate dietary control, physical activity, and healthcare use, respectively. The data are shown in Fig. 3.

Table 2
Changes in glycated hemoglobin (HbA1c) and ambulatory glucose profile (AGP) before, during, and after Ramadan (n = 93).

Metrics[a]	Before/During Ramadan			During/After Ramadan		
	Before	During	P value[b]	During	After	P value[b]
Glycated hemoglobin (A1c)	8.2 ± 0.4	7.9 ± 0.3	<0.001*	7.9 ± 0.3	8.1 ± 0.4	<0.001*
Ambulatory Glucose Profile (AGP)						
Average glucose (mg/dL)	187.5 ± 16.3	180.6 ± 12.6	0.001*	180.6 ± 12.6	186 ± 22.1	0.026*
Glucose Management Indicator (GMI %)	8.0 ± 0.4	7.9 ± 0.3	<0.001*	7.9 ± 0.3	7.9 ± 0.4	0.290
Glycemic variability (GV %)	34.9 ± 7.0	32.8 ± 6.4	0.043*	32.8 ± 6.4	35.7 ± 6.5	0.005*
Target Range 70–180 mg/dL (TIR %)	43.3 ± 10.6	52.4 ± 13.4	<0.001*	52.4 ± 13.4	44.4 ± 12.2	<0.001*
Time above Range 181–250 mg/dL (TAR %)	30.0 ± 6.4	23.9 ± 6.1	<0.001*	23.9 ± 6.1	29.9 ± 6.3	<0.001*
% TAR above 250 mg/dL	6 ± 2.6	6.6 ± 2.0	0.081	6.6 ± 2.0	5.9 ± 2.5	0.034*
% TBR below 70 mg/dL (54–69 mg/dL)	0.6 ± 0.7	0.77 ± 0.7	0.092	0.77 ± 0.7	0.61 ± 0.8	0.148
% TBR below 54 mg/dL	0.14 ± 0.4	0.31 ± 0.6	<0.001*	0.31 ± 0.6	0.16 ± 0.4	0.002*
% Time Sensor is Active	82.0 ± 6.3	86.4 ± 5.5	<0.001*	86.4 ± 5.5	81.6 ± 6.3	<0.001*
Low glucose events (episodes/28 days)	2.2 ± 1.2	2.1 ± 1.5	0.771	2.1 ± 1.5	1.7 ± 1.1	0.058

TBR: Time below Range.
[a] Numerical data are presented as the means (SD).
[b] Paired sample *t*-test.
[*] P values less than 0.05 are considered to indicate statistical significance.

3.5. *Association between self-management and glucose changes during ramadan*

There was no significant correlation between the four subscales of the DSMQ and HbA1c. However, a significant positive correlation was observed between the DSMQ sum scale and HbA1c (ρ = 0.230; p = 0.027) (Table 5). In addition, there was a significant positive correlation between the DSMQ sum and % TBR below 54 mg/dL (ρ = 0.219; p = 0.035).

Moreover, there was a significant positive correlation between the healthcare use subscale and AGP metrics, including glucose variability (ρ = 0.207; p = 0.047) and %Time Sensor is Active (ρ = 0.238; p = 0.021). In addition, a positive correlation was found between the physical activity subscale and % in the target 70–180 mg/dl group (ρ = 0.214; p = 0.039).

It was found that there was no significant correlation between the DSMQ scores and HbA1c among males, females, patients aged 50 years or less, and those with age higher than 50 years old (Table 6).

4. Discussion

Fasting during Ramadan is associated with favorable outcomes for healthy individuals because of improved insulin sensitivity [30,31]. However, there is conflicting evidence regarding its effect on the biochemical and glycemic profiles of T2DM patients [32–34]. This study

Table 3
Changes in glycated hemoglobin (HbA1c) and ambulatory glucose profile (AGP) before, during, and after Ramadan regarding gender and age (n = 93).

Variables	Gender			Age		
	Male	Female	P value	≤50 years	>50 years	P value
Glycated hemoglobin (A1c)						
Before/During Ramadan	−0.29 ± 0.21	−0.25 ± 0.28	0.488	−0.25 ± 0.24	−0.32 ± 0.27	0.217
During/After Ramadan	0.16 ± 0.35	0.17 ± 0.27	0.822	0.16 ± 0.34	0.17 ± 0.26	0.950
Average glucose (mg/dL)						
Before/During Ramadan	−5.69 ± 16.33	−8.11 ± 21.29	0.538	−7.87 ± 20.36	−4.37 ± 14.51	0.418
During/After Ramadan	8.13 ± 24.20	2.49 ± 21.55	0.240	5.18 ± 23.99	5.93 ± 20.83	0.888
Glucose Management Indicator (GMI %)						
Before/During Ramadan	−0.15 ± 0.13	−0.16 ± 0.17	0.910	−0.15 ± 0.12	−0.16 ± 0.21	0.893
During/After Ramadan	0.035 ± 0.19	0.0022 ± 0.16	0.364	0.02 ± 0.18	0.02 ± 0.18	0.920
Glycemic variability (GV %)						
Before/During Ramadan	−1.68 ± 9.39	−2.72 ± 11.16	0.629	−2.04 ± 10.71	−2.54 ± 9.19	0.832
During/After Ramadan	3.54 ± 9.46	2.26 ± 9.97	0.526	3.31 ± 9.99	1.98 ± 8.96	0.550
Target Range 70–180 mg/dL (TIR %)						
Before/During Ramadan	9.60 ± 18.27	8.53 ± 15.97	0.765	8.62 ± 17.69	10.22 ± 15.84	0.684
During/After Ramadan	−8.66 ± 18.55	−7.38 ± 17.07	0.737	−9.09 ± 18.37	−5.44 ± 17.33	0.380
Time above Range 181–250 mg/dL (TAR %)						
Before/During Ramadan	−4.32 ± 5.97	−7.93 ± 7.59	0.012	−5.44 ± 7.39	−7.59 ± 5.81	0.181
During/After Ramadan	4.27 ± 6.71	7.67 ± 7.98	0.028	5.45 ± 7.66	7.03 ± 7.12	0.346
% TAR above 250 mg/Dl						
Before/During Ramadan	0.90 ± 3.55	0.24 ± 2.72	0.313	0.17 ± 3.19	1.58 ± 2.98	0.053
During/After Ramadan	−0.95 ± 3.46	−0.40 ± 2.63	0.391	−0.40 ± 3.05	−1.38 ± 3.12	0.169
% TBR below 70 mg/dL (54–69 mg/dL)						
Before/During Ramadan	0.27 ± 0.96	0.07 ± 0.99	0.315	0.27 ± 0.99	−0.07 ± 0.92	0.120
During/After Ramadan	−0.23 ± 1.03	0.96 ± 1.10	0.529	−0.27 ± 1.10	0.11 ± 0.93	0.116
% TBR below 54 mg/dL						
Before/During Ramadan	0.10 ± 0.42	0.24 ± 0.48	0.142	0.17 ± 0.48	0.19 ± 0.39	0.860
During/After Ramadan	−0.10 ± 0.37	−0.20 ± 0.55	0.330	−0.18 ± 0.49	−0.07 ± 0.38	0.313
% Time Sensor is Active						
Before/During Ramadan	4.06 ± 7.74	4.80 ± 8.46	0.662	4.82 ± 7.77	3.44 ± 8.80	0.459
During/After Ramadan	−4.81 ± 7.56	−4.80 ± 8.46	0.994	−5.36 ± 7.59	−3.44 ± 8.80	0.294
Low glucose events (episodes/28 days)						

(*continued on next page*)

Table 3 (*continued*)

Variables	Gender			Age		
	Male	Female	P value	≤50 years	>50 years	P value
Before/ During Ramadan	0.25 ± 1.77	−0.38 ± 1.75	0.089	0.18 ± 1.82	−0.63 ± 1.55	0.045
During/ After Ramadan	−0.73 ± 2.00	0.00 ± 1.70	0.062	−0.53 ± 1.94	0.00 ± 1.75	0.222

P values less than 0.05 are considered to indicate statistical significance.
Numerical data are presented as the means (SD).

aimed to examine glycemic changes among T2DM patients not treated with intensive insulin regimens before, during, or after Ramadan in Saudi Arabia.

To date, published articles extensively analyzing metabolic changes during Ramadan fasting are mainly based on data collected from patients with T1DM or on conventional self-monitoring blood glucose (SMBG) in individuals with T2DM. Therefore, to our knowledge, this is the first study to investigate glycemic variability throughout Ramadan in T2DM patients in an actual clinical practice setting using isCGM. It also stratifies the changes in the HBA1c and AGP-derived metrics among those populations at three time points, pre, during, and post-Ramadan.

Our study included T2DM patients who were not treated with intensive insulin therapy and who had a mean age of 48 years and a mean duration of diabetes of seven years. It was previously shown that increasing the age and duration of diabetes increases the risk score for Ramadan fasting according to the IDF-DAR risk score [35]. However, according to our findings, Ramadan fasting appears to confer benefits to glycemia control among patients with T2DM, with improvements in the main parameters of diabetes, including HbA1c, average glucose, GMI, GV, TIR (70–180 mg/dL), and TAR (181–250 mg/dL).

Indeed, a significant reduction in HbA1c was observed during Ramadan compared to pre- and post-Ramadan; HbA1c decreased significantly during Ramadan compared to pre- and post-Ramadan ($p < 0.001$). Similar findings were found in several studies in the literature, which reported that fasting during Ramadan has a positive effect on HBA1c levels among T2DM patients [19,32,36,37]. Conversely, Saadane et al. revealed no significant change in HbA1c before, during, or after Ramadan [38].

Ramadan fasting is a prominent example of intermittent fasting [29]. However, conflicting results have been reported regarding the impact of intermittent fasting on T2DM. A recent systematic review has shown that intermitted energy restriction and periodic fasting result in an improvement in glucose regulation in the short term and increase the opportunity for dose reduction of anti-diabetic medications among T2DM patients [26]. However, Carter et al. have observed that intermitted energy restriction has a comparable reduction effect on HbA1c compared with continuous energy restriction over a 12-month follow-up period of T2DM patients [27]. Moreover, Borgundvaag et al. have also reported a comparable impact of intermitted fasting and standard diet on glycemic control, lipid profile, and blood pressure of patients with T2DM [28], highlighting the need for further research examining different intermitted fasting protocols with longer follow-up periods.

In the current study, a significant improvement in average glucose levels during the Ramadan period was observed. Similarly, Bashier et al. reported that average glucose improved significantly among T2DM patients after Ramadan fasting ($p = 0.013$) [32,37].

GV refers to the frequency of variation from the average glucose level, and the coefficient of variation is considered a reliable metric of glucose variability. A recommended GV value less than 36 % indicates low glucose variability and stable glycemia [39–41]. In our study, GV decreased during Ramadan (32.8 %) compared to before Ramadan (34.9 %, $p = 0.043$) but then increased after Ramadan (35.7 %, $p = 0.005$), indicating more stable glucose levels during Ramadan fasting. However, Harbuwono et al. demonstrated that GV did not change significantly among T2DM patients during the fasting Ramadan period or the nonfasting period post-Ramadan [42]. Aldawi et al. also found that there was no significant change in GV early, late, or post-Ramadan among T2DM patients using CGM [2].

The improvement in glucose was further supported by the increase in the percentage of time spent in the target glucose range (70–180 mg/dL) (before Ramadan: 43.3 %, during Ramadan: 52.4 %, and after Ramadan:

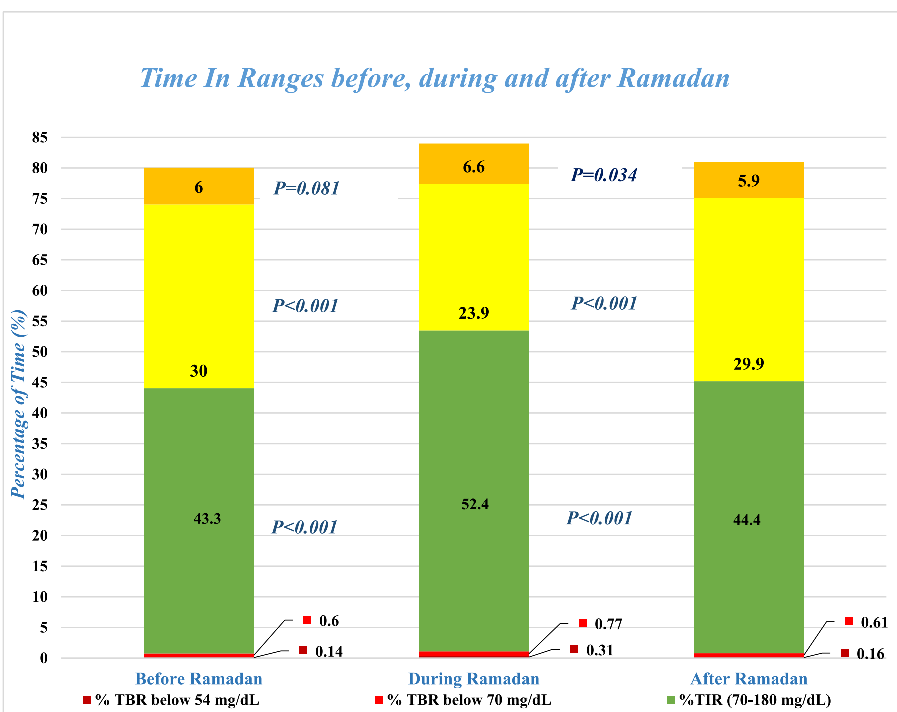

Fig. 2. Time in ranges before, during and after ramadan.

Table 4
Diabetes Self-Management Questionnaire (DSMQ) response during Ramadan (n = 93).

	Applies to me very much (3)	Applies to me to a considerable degree (2)	Applies to me to some degree (1)	Does not apply to me (0)
Glucose management				
1. I check my blood sugar levels with care and attention.	63 (67.7 %)	30 (32.3 %)	0 (0 %)	0 (0 %)
4. I take my diabetes medication (e.g. insulin, tablets) as prescribed.	27 (29 %)	53 (57 %)	13 (14 %)	0 (0 %)
6. I record my blood sugar levels regularly (or analyze the value chart with my blood glucose meter)	76 (81.7 %)	17 (18.3 %)	0 (0 %)	0 (0 %)
10. I do not check my blood sugar levels frequently enough as would be required for achieving good blood glucose control.	0 (0 %)	0 (0 %)	12 (12.9 %)	81 (87.1 %)
12. I tend to forget to take or skip my diabetes medication (e.g. insulin, tablets).	0 (0 %)	4 (4.3 %)	22 (23.7 %)	67 (72 %)
Dietary control				
2. The food I choose to eat makes it easy to achieve optimal blood sugar levels.	6 (6.5 %)	46 (49.5 %)	29 (31.2 %)	12 (12.9 %)
5. Occasionally, I eat lots of sweets or other foods rich in carbohydrates.	23 (24.7 %)	41 (44.1 %)	29 (31.2 %)	0 (0 %)
9. I strictly follow the dietary recommendations given by my doctor or diabetes specialist.	3 (3.2 %)	20 (21.5 %)	60 (64.5 %)	10 (10.8 %)
13. Sometimes I have real 'food binges' (not triggered by hypoglycemia).	6 (6.4 %)	35 (37.6 %)	34 (36.6)	18 (19.4 %)
Physical activity				
8. I do regular physical activity to achieve optimal blood sugar levels.	1 (1.1 %)	9 (9.7 %)	60 (64.5 %)	23 (24.7 %)
11. I avoid physical activity, although it would improve my diabetes.	6 (6.5 %)	48 (51.6 %)	35 (37.6 %)	4 (4.3 %)
15. I tend to skip planned physical activity	15 (16.1 %)	55 (59.1 %)	21 (22.6 %)	2 (2.2 %)
Health-care use				
3. I keep all doctors' appointments recommended for my diabetes treatment.	13 (14 %)	55 (59.1 %)	20 (21.5 %)	5 (5.4 %)
7. I tend to avoid diabetes-related doctors' appointments	15 (16.1 %)	39 (41.9 %)	27 (29 %)	12 (12.9 %)
14. Regarding my diabetes care, I should see my medical practitioner(s) more often.	1 (1.1 %)	7 (7.5 %)	48 (51.6 %)	37 (39.8 %)
Self-care				
16. My diabetes self-care is poor.	2 (2.2 %)	15 (16.1 %)	49 (52.7 %)	27 (29 %)

44.4 %, $p < 0.001$) and the decrease in the percentage of time spent above the threshold of 181–250 mg/dL (before Ramadan: 30 %, during Ramadan: 23.9 %, and after Ramadan: 29.9 %; $p < 0.001$). On the other hand, patients with a TBR less than 54 mg/dL were significantly longer during Ramadan than before and after Ramadan. Despite this, the number of reported hypoglycemic events did not significantly change, suggesting that while there was an increase in time spent in the hypoglycemic range during Ramadan, this increase may not have translated into clinically significant events.

Overall, the findings of the glycemic parameters in the present study indicate a positive response to the challenges posed by fasting, with more stable glucose levels and more time within the optimal range. In contrast to our findings, no significant difference in the AGP before and after Ramadan was observed among insulin-treated, non-insulin-treated, and oral anti-diabetic-treated T2DM patients in previous studies [2,33,42]. Furthermore, Lessan et al. suggested that fasting during Ramadan caused neither overall deterioration nor improvement in most patients with good glucose control [17]. These differences might be explained by differences in age, duration of diabetes, treatment regimens, and lifestyle and dietary modifications [43,44].

Diet, exercise, and the use of antidiabetic medications can maintain blood glucose levels; however, any change in these factors may cause fluctuations in blood glucose levels and hyperglycemia or hypoglycemia [5,14,15]. Moreover, the risk of hypoglycemia varies depending on the treatment regimen, previous history of hypoglycemia before Ramadan, and the degree of risk stratification for Ramadan fasting [19,45]. Interestingly, fasting during Ramadan did not have a negative impact on most of our patients, and no patients visited the hospital because of glycemic issues. In addition, the number of reported low glucose events did not change significantly pre, during, or post-Ramdan. Therefore, the current study supported the idea that fasting during Ramadan is unlikely to cause a significant risk for well-controlled T2DM patients who are not treated with intensive insulin regimens. Similarly, previous Turkish studies that included patients with T2DM revealed that Ramadan did not have any negative effects associated with fasting in this group of patients [6,32]. In addition, Harbuwono et al. revealed that there was no difference in the rate of hypoglycemia between the Ramadan and post-Ramadan periods, with no evidence of symptomatic hypoglycemia or hyperglycemia [42].

Self-care management is essential for patients with diabetes to maintain their glucose levels and health and to help them reduce the risk of complications from diabetes. It includes diet control, increasing physical exercise, and regularly monitoring blood glucose [46]. However, our study indicated that participants exhibited moderate overall diabetes self-management behaviors during Ramadan, as reflected by a median total DSMQ score of 6.2 (0.7) out of 10. In addition, approximately one-third of the participants reported inadequate self-care behaviors during Ramadan. In contrast to our results, a Saudi study revealed that self-care management among patients with diabetes was high. However, this study was not conducted during Ramadan [47]. The difference in self-care management level might be associated with several factors, such as knowledge level, adherence, educational programs, the patient's level of self-efficacy, and lifestyle changes during Ramadan.

Previous studies have consistently demonstrated the positive impact of adequate self-management behaviors and glycemic control [48,49]. Alodhayani et al. reported a negative correlation between elevated HbA1c levels and both dietary control and physical activity, while a positive correlation was observed with healthcare utilization. Additionally, glucose management and physical activity subscales were predictive of lower HbA1c levels [47]. Our study further supports these findings by revealing a positive correlation between the physical activity subscale and the percentage of time spent within the target glucose range (TIR, 70–180 mg/dL).

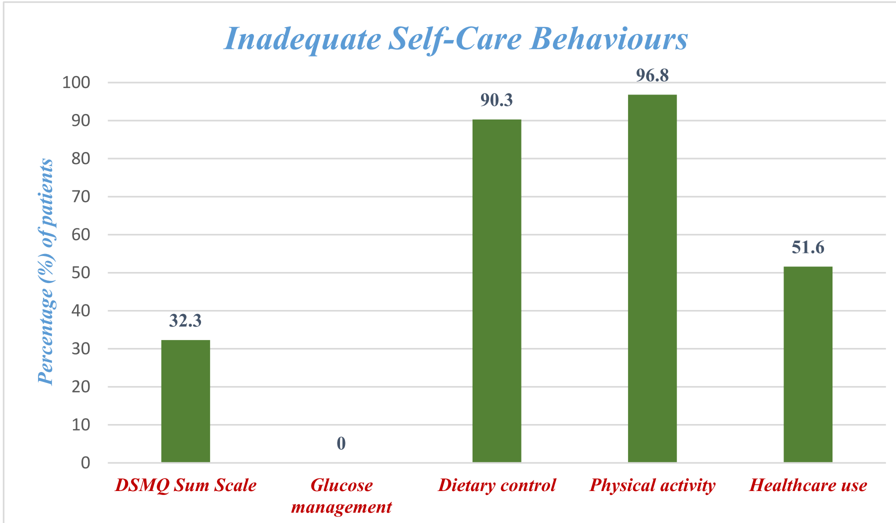

Fig. 3. Classification of diabetes self-care behaviors according to the DSMQ

Table 5
Correlations between the DSMQ scores and HbA1c and ambulatory glucose profile (AGP) metrics during Ramadan (n = 93).

Parameters	Glucose Management		Dietary Control		Physical Activity		Health-Care Use		Sum Scale	
	Correlation coefficient	P value[a]	Correlation coefficient	P value[a]	Correlation coefficient	P value	Correlation coefficient	P value	Correlation coefficient	P value
HbA1c	0.031	0.765	−0.032	0.764	0.195	0.061	0.133	0.205	0.230	0.027*
Average glucose (mg/dL)	−0.045	0.672	0.013	0.899	0.084	0.422	0.064	0.542	0.055	0.601
GMI%	0.079	0.453	−0.045	0.666	0.162	0.122	0.063	0.547	0.173	0.097
GV%	0.140	0.180	−0.140	0.180	−0.024	0.816	0.207	0.047*	0.082	0.437
%TIR 70–180 mg/dL	−0.108	0.303	0.147	0.160	0.214	0.039*	−0.130	0.214	0.052	0.619
%TAR 181–250 mg/dL	0.020	0.847	0.054	0.604	0.007	0.946	0.062	0.555	−0.013	0.899
%above 250 mg/dL	−0.015	0.888	−0.039	0.711	0.072	0.494	0.051	0.628	0.060	0.565
%Below 70 mg/dL	−0.059	0.573	0.179	0.086	−0.060	0.566	−0.139	0.183	−0.060	0.569
% Below 54 mg/dL	0.180	0.084	0.108	0.302	0.190	0.068	−0.019	0.858	0.219	0.035*
%Time Sensor is Active	−0.182	0.081	0.087	0.405	0.069	0.509	0.238	0.021*	0.163	0.118
Low glucose events	−0.047	0.654	0.072	0.494	−0.025	0.814	0.127	0.227	0.131	0.212

[a] Spearman's rank order (two-tailed test) for DSMQ scales with HbA1c and AGP metrics.
* Correlation is significant at the 0.05 level (2-tailed).

Table 6
Correlations between the DSMQ scores and HbA1c during Ramadan stratified by gender and age (n = 93).

Variables		Parameters	Sum Scale of DSMQ scores	
			Correlation coefficient	P value
Gender	Male	**HbA1c during Ramadan**	0.110	0.455
	Female	**HbA1c during Ramadan**	0.246	0.103
Age	≤50 years	**HbA1c during Ramadan**	0.177	0.156
	>50 years	**HbA1c during Ramadan**	0.234	0.239

Correlation is significant at the 0.05 level (2-tailed).

4.1. Limitations

This study has several limitations, including the small sample size, the observational nature of the study design, and the performance of the study in a single center. Moreover, sleeping patterns, the intensity of physical activity, and the components of the participants' diets were not recorded, which might prevent further exploration of the study findings. Another source of limitations is the potential bias associated with the participants' self-reports of their diabetes self-management practices.

5. Conclusion

In summary, the present study revealed a significant improvement in HBA1c levels and AGP indices in T2DM patients not treated with intensive insulin regimens during Ramadan compared with pre- and post-Ramadan. Therefore, Ramadan fasting seems to be safe for T2DM patients without diabetic complications and without causing serious adverse glycemic events. However, one-third of patients reported inadequate self-care behaviors during Ramadan, highlighting the need for effective individualized structured educational programs aimed at improving patients' self-care management of T2DM patients during Ramadan. Further studies are required to examine the factors associated with glucose improvement during Ramadan, as well as the self-care behaviors of T2DM patients.

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Availability of data and materials

The datasets used and/or analyzed during the current investigation are available upon reasonable request from the corresponding author.

Ethics approval

This research was performed according to the guidelines of the Declaration of Helsinki, and approval was granted by the Research and Ethics Committee of PSMMC, Riyadh, Saudi Arabia (IRB# # 1394).

Informed consent

Informed consent was obtained from the patients prior to enrollment in the study.

Consent for publication

Not applicable.

CRediT authorship contribution statement

Ayman Al Hayek: Writing – review & editing, Resources, Conceptualization. **Wael M. Al Zahrani:** Writing – review & editing, Resources, Conceptualization. **Mohamed Abdulaziz Al Dawish:** Writing – review & editing, Resources, Conceptualization.

Declaration of competing interest

All authors listed have no conflict of interest, financial or otherwise.

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