

ACUTE EFFECTS OF VARIOUS EXERCISE MODALITIES ON GLYCEMIC CONTROL IN PATIENTS WITH TYPE 2 DIABETES: A SYSTEMATIC REVIEW

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Type 2 diabetes mellitus (T2DM) is characterized by impaired glycemic control, which increases the risk of cardiovascular and metabolic complications. Exercise is a key non-pharmacological intervention known to improve blood glucose regulation, but the acute effects of different exercise modalities on glycemic control in T2DM remain unclear. The aim of this systematic review was to critically analyze and synthesize the existing body of research on the acute effects of various exercise modalities on glycemic control in patients with T2DM.

This systematic review included studies involving adults (≥ 18 years) with T2DM where structured exercise program is the primary or significant intervention, assessing outcomes related to glycemic control (HbA1c, and fasting glucose). A comprehensive search was conducted across two electronic databases (Web of Science and PubMed) using structured search terms like "acute", "exercise", "type 2 diabetes", and "glycemic control". Study selection involved two independent reviewers screening articles, with disagreements resolved through discussion or third-party consultation, followed by detailed data extraction on study characteristics, intervention details, and outcomes.

Ten studies were identified that met all inclusion criteria. This systematic review highlights that moderate-intensity continuous training and high-intensity interval training have positive acute effects on glycemic control in individuals with T2DM.

These findings suggest that both modalities are effective non-pharmacological strategies for optimizing glycemic control in patients T2DM.

Keywords: exercise, fitness, glucose, diabetes mellitus

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INTRODUCTION

The prevalence of type 2 diabetes mellitus (T2DM) is projected to rise dramatically, with an estimated 642 million individuals affected by 2040, which will present significant social and economic challenges (1). Furthermore, despite pharmacological treatments, previous research (2) indicates that a majority of T2DM individuals continue to experience prolonged periods of hyperglycemia throughout the day. Consequently, these patients remain at elevated risk for diabetes-related complications and cardiovascular disease due to persistent hyperglycemia and elevated postprandial glucose levels. Thus, the development of effective and accessible interventions is essential for mitigating diabetes-related complications and improving the life expectancy of individuals with T2DM.

Exercise is one of the most effective non-pharmacological methods for the prevention and treatment of T2DM, due to its benefits on long-term glycemic control and other clinically significant cardiometabolic parameters, such as body composition, cardiorespiratory fitness, and blood pressure. However, previous studies (3, 4) have predominantly utilized glycated hemoglobin (HbA1C) as the primary indicator of glycemic control. HbA1C is a marker used to assess long-term glycemic regulation, with evidence suggesting that a minimum of 12 weeks is required to observe significant improvements. Nevertheless, substantial variability in findings has been observed when evaluating this parameter in relation to sex, ethnicity, or health status (5). Moreover, HbA1C does not provide information on acute glucose fluctuations associated with stress, immediate dietary intake, or exercise (6). Conversely, evidence (7) suggests that acute daily exercise interventions may have a more pronounced effect on enhancing long-term glycemic control compared to the chronic adaptations achieved through various exercise modalities. Given that other parameters of glycemic control, such as 24-h mean glucose levels, postprandial glucose and time spent in hyperglycemia (%) are associated with an increased risk of additional complications (8, 9) and subsequent alterations in HbA1C; it is imperative to analyze how acute exercise influences these markers.

Nevertheless, there remains the ongoing debate regarding which exercise modality is most effective and well-tolerated for individuals with T2DM. A single session of resistance training (RT) (10) and moderate-intensity continuous training (MICT) (11) have been shown to improve glucose uptake,

with effects persisting for up to 48 hours post-exercise (12). Moreover, previous research (13–15) indicates that glycemic control and glucose utilization are more closely associated with exercise intensity, challenging the traditional view that standard exercise regimens serve as the “gold standard” for optimizing glycemic outcomes. Thus, a comprehensive understanding of these acute exercise effects may provide valuable insights for optimizing exercise prescriptions aimed at reducing cardiometabolic risk and improving overall glycemic stability in patients with T2DM. Therefore, the aim of this systematic review was to examine the effects of acute exercise on continuous glucose monitoring (CGM) outcomes in T2DM, with a primary focus on 24-h mean glucose levels, postprandial glucose levels, and time spent in hyperglycemia.

METHODS

Data source and search strategy

Two major electronic databases, Web of Science and MEDLINE (accessed via PubMed), were searched from 2014 to Sep 20, 2024. The search was limited to the past ten years to capture the most recent advancements in the field of acute effects of different exercise modalities on glycemic control in T2DM patients. The key terms selected for the search strategy were associated with exercise, T2DM, and CGM. The search included the following keywords: „type 2 diabetes”, “diabetes mellitus type 2” “T2DM”, “glycemic control”, “glycemia”, “blood glucose”, “continuous glucose monitoring system”, “CGM”, “24-h mean glucose levels”, “acute effects” “exercise”, “MICT”, “HIIT”, “resistance training”, “hyperglycemia”, “time spent in hyperglycemia”, “postprandial glucose”, and “postprandial glycemia”. These terms were utilized to capture relevant literature on glycemic regulation and exercise interventions in T2DM patients, focusing on studies that monitor glucose levels through CGM technology.

Eligibility criteria

Two different authors (A.L and N.T.) independently assessed the eligibility criteria of the selected studies. The following inclusion criteria were based on the PICO strategy (P—participants, I—intervention, C—comparison, O—outcome): (1) Adult patients (18–65) diagnosed with T2DM free of complications and any other major health issue or disease

(e.g., cardiovascular diseases, cancer); (2) We considered both randomized and non-randomized studies published in peer-reviewed journals with a Journal Citation Reports Index; studies published in English; (3) Studies with a duration of ≤ 2 weeks were included if they investigated the acute effects of different exercise modalities (RT, MICT, HIIT) specified by frequency, intensity, type, and duration; (4) Comparison group including no exercise condition or different exercise modality; (5) Outcome measures included at least one CGM glycemic control parameter (24-h mean glucose, postprandial glucose levels and/or time spent in hyperglycemia).

Studies that met any of the following criteria were excluded: studies including athletes, recreationally active population or clinical populations diagnosed with any other chronic disease (i.e., cardiovascular diseases, cancer), long-term (> 2 weeks) investigating the effects of different exercise modalities on glycemic control; studies lacking defined exercise intensity, and ineligible publication types (e.g., reviews, editorials, letters, commentaries, unpublished studies, guidelines, cross-sectional or case reports studies) (Table 1).

Table 1. Eligibility criteria

	Inclusion criteria	Exclusion criteria
Population	1. Patients with T2DM aged 18-65.	1. Healthy population; 2. Professional and recreational athletes; 3. Patients with T2DM below 18 years old and above 65 years old.
Intervention	1. Exercise interventions (RT, MICT, HIIT) that lasted ≤ 2 weeks.	MICT, HIIT, SIT, structured training programs; Acute studies.
Comparator	Control group and/or different exercise modality.	
Outcome	Glycemic control (24-h mean glucose, postprandial glucose levels and time spent in hyperglycemia).	No data on at least for one outcome

Data collection and extraction process

An EndNote library was created for data collection (Clarivate Analytics, New York, NY, USA). The extracted data from the included were: (1) study (first author's surname and year of publication); (2) sample size (male/female); (3) groups; (4) characteristics of the study sample, i.e., age (expressed as mean and standard deviation or range), diabetes duration (expressed as mean and standard deviation or range), medication; (5) study design; (6) intervention characteristics (activity description, intensity and type of activity); (7) outcomes: glycemic control (i.e., 24-h mean glucose, postprandial glucose levels, time spent in hyperglycemia (%)). When data were graphically presented, we extracted data using WebPlotDigitizer online software. Data collection and extraction were independently double-checked by two authors (A.L. and N.T.).

RESULTS

Study selection

The initial database search identified a total of 4,730 articles. After the removal of 1,760 duplicates and the exclusion of 2,685 studies deemed irrelevant based on their titles and abstracts, 285 studies remained for further evaluation. Upon thorough screening of titles and abstracts, an additional 218 studies were excluded, resulting in 67 studies that progressed to full-text assessment. During the detailed review phase, 57 studies were excluded for the following reasons: ineligible study sample ($n = 19$), ineligible study design ($n = 11$) and ineligible intervention ($n = 27$). The selection process is depicted in Figure 1. Finally, 10 studies were included in the final systematic review and meta-analysis (Figure 1).

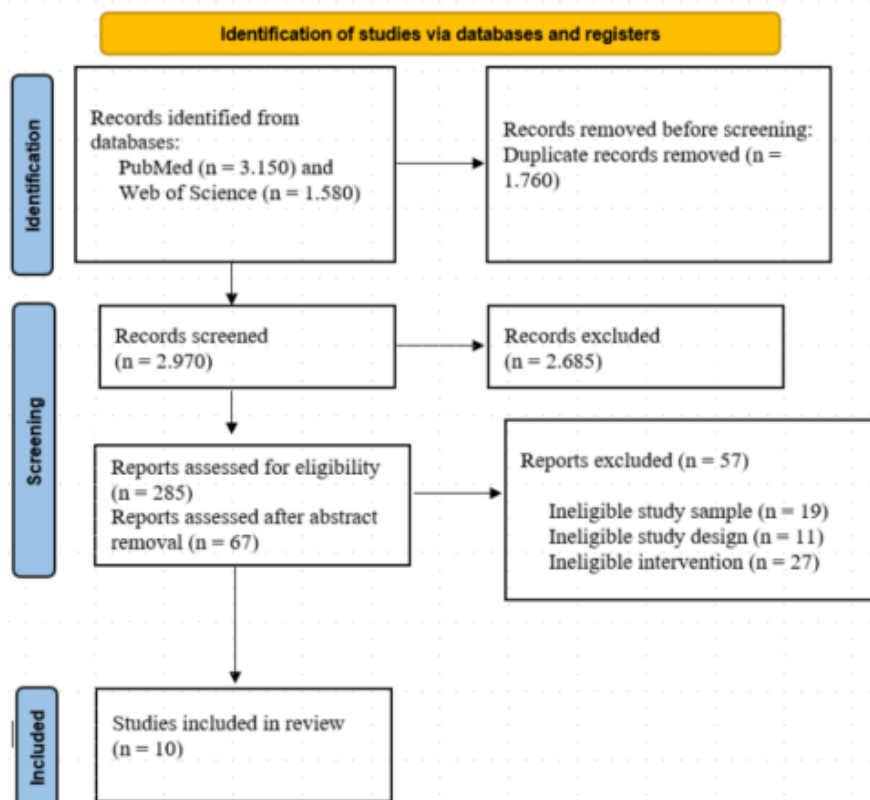


Figure 1. The updated guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flowchart of search and eligible study selection

Sample characteristics

Total sample included in this systematic re-view consisted of 194 participants with T2DM. Among the total number of participants, 62 were female. The number of participants ranged from seven (16) to 73 participants (17). All participants were on hypoglycemic oral therapy, while in three studies (18-20), it was reported that participants were also undergoing insulin therapy (Table 2).

Intervention characteristics

All experimental interventions were designed to investigate the acute effects of aerobic training modalities, specifically MICT and HIIT on glycemic control. The predominant forms of exercise included cycle ergometry and treadmill running. A variety of parameters were utilized to quantify exercise intensity (e.g., Wmax, HRmax, HRR) resulting in challenges when defining a specific intensity range. The highest intensity recorded was "all-out" (21) and 95% HRmax (22) (Table 3).

Table 2. Characteristics of included studies and participants

Study	Sample size (M/F)	Groups (n)	Characteristics of the study sample		
			Age (y)	Diabetes duration (y)	Medication
Gillen et al. (16)	7	HIIT CONT	62 ± 3	< 1	Oral medication
Van Dijk (18)	30 (30)	MICT CONT	60. ± 6	8.7 ± 7.5	Insulin therapy and oral medication
Terada et al. (23)	10 (8/2)	HIIT _{fast} HIIT _{fed} MICT _{fast} MICT _{fed} CONT	40 – 75	NA	Oral medication
Erickson et al. (24)	8 (5/3)	NA	60 ± 10.7	NA	Oral medication
Li et al. (25)	29 (22/7)	NA	51 ± 11.2	5.7 ± 6.0	Oral medication
Metcalfe et al. (21)	11 (M)	HIIT (11) REHIT (11) MICT (11) CONT (11)	52 ± 6	4 ± 3	Oral medication
Rees et al. (17)	73 (33/40)	NA	63.5 ± 9.1	9.5 ± 6.0	Oral medication
Iida et al. (19)	11 (7/4)	MICT (11) CONT (11)	63.9 ± 15.4	NA	Insulin therapy and oral medication
Zhang et al. (20)	15 (9/6)	WG (15) JG (15) CONT (15)	54.7 ± 5.8	5.3 ± 4.4	Insulin therapy and oral medication
Marcotte-Chénard et al. (22)	14 (NA)	HIIT _{4x4} (14) HIIT _{10x1} (14) CONT (14)	69.9 ± 4.3	10.2 ± 6.4	Oral medication

Legend: HIIT — high-intensity interval training; MICT — moderate continuous training; CONT — control group; HIIT fast — high-intensity interval training in fasted state; HIIT fed — HIIT in fed state; REHIT — reduced — exertion high intensity interval training; WG — walking group; JG — jogging group; NA — non applicable; HIIT 4x4 — high volume high intensity interval training; HIIT 10x1 — low volume high-intensity interval training

Outcomes

Mean 24-h mean glucose levels were reported in eight studies (16–19, 21–24). Moreover, outcome measures for glycemic control were obtained for postprandial glucose levels from seven studies (16, 17, 19, 20, 23–25) and time spent in from four studies (16, 18, 21, 22) (Table 3).

DISCUSSION

The main finding of the systematic review was that different exercise modalities have an acute impact on improving overall glycemic control in patients with T2DM by reducing 24-h mean glucose levels, decreasing postprandial glucose levels, and lowering the time spent in hyperglycemia.

24-h mean glucose levels

Our review revealed that various exercise modalities positively affect the reduction of 24-hour glucose levels. Our findings are consistent with previous meta-analyses (26, 27) which reported significant reductions in 24-hour mean glucose levels by 5 mmol/L (26) and 8 mmol/L (27) following exercise, respectively. Moreover, the analysis suggests that HIIT may be more effective in reducing glycemic concentrations compared to MICT. Some authors (18, 28) attribute this effect to the relationship between 24-h glucose levels and HbA1C, indicating that moderate-intensity activities might have a greater impact on long-term glycemic control. Additionally, 24-h glucose concentrations are influenced by various factors such as sex (27) and baseline glycemic control (18, 27). It has been emphasized

Table 3. Characteristics of exercise interventions

Study	Study design	Characteristics of the experimental interventions		Outcomes		
		Intervention characteristics	Type	Mean 24-h glucose	PPG	Time spent in hyperglycemia (%)
Gillen et al. (16)	Acute crossover	HIIT – 10 x 60 s (85% HR _{max}) CONT – No exercise	Cycling/cycle ergometer	↔	↓*	↓*
Van Dijk et al. (18)	Acute crossover	MICT – 2 x 30 min (40 W _{max}) CONT – no exercise	Cycling/cycle ergometer	↓ (MICT) ↔ (CONT)		↓* (MICT) ↔ (CONT)
Terada et al. (23)	Acute crossover	HIIT – 15 x 3 (100% VO _{2peak}) MICT – 45 min (55% VO _{2peak}) CONT – no exercise	Walking/ treadmill	↓* (HIIT _{fast}) ↓* (HIIT _{fed}) ↔ (MICT _{fast}) ↔ (MICT _{fed}) ↔ (CONT) (HIIT _{fast} vs. HIIT _{fed}) ↓* (HIIT _{fast}) ↓*	↓* (HIIT _{fast}) ↓* (HIIT _{fed}) ↓* (MICT _{fast}) ↓* (MICT _{fed}) ↔ (CONT) (HIIT _{fast} vs. HIIT _{fed} vs. MICT _{fast} vs. MICT _{fed}) ↓* (HIIT _{fast}) ↓*	NA
Erickson et al. (24)	Acute crossover	3 x 10 min (50% VO _{2peak})	Walking/ treadmill	↓*	↓*	NA
Li et al. (25)	Acute crossover	MICT – 20 min (40% HRR) CONT – no exercise	Walking/ treadmill	NA	↓* (MICT) ↔ (CONT)	NA
Metcalfe et al. (21)	Acute crossover	HIIT – 10 x 60 s (85% W _{max}) REHIT - 10 min with 2 all-out sprints MICT - 30 min at an intensity equivalent to 50% of W _{max} CONT – no exercise	Cycling	↔ (HIIT) REHIT ↓* (MICT) ↔ (CONT)	NA	HIIT ↓* REHIT ↓* MICT ↓* CONT ↔
Rees et al. (17)	Acute crossover	MICT – 50 min at 5 km/h CONT – no exercise	Walking/ treadmill	↓* (MICT) ↔ (CONT)	↔ (MICT) ↔ (CONT)	NA
Iida et al. (19)	Acute crossover	MICT – 3 x (15 min) (40% HR _{max}) CONT – no exercise	Walking/ treadmill	↓* (MICT) ↔ (CONT)	↓* (MICT) (↔) CONT	NA
Zhang et al. (21)	Acute crossover	WG – 2 km at 4-4.5 km/h JG – 2 km at 5-6 km/h CONT – no exercise	Walking, jogging/ treadmill	NA	↓* (WG) ↓* (JG) ↔ (CONT) ↓* (WG vs. JG) (JG)	NA
Marcotte-Chénard et al. (22)	Acute crossover	HIIT _{4x4} – 4 x 4 min (90% HR _{max}) HIIT _{10x1} – 10 x 1 min (90% HR _{max}) CONT – no exercise	Cycling/cycle ergometer	↔ (HIIT _{4x4}) ↔ (HIIT _{10x1}) ↔ (CONT)		↔ (HIIT _{4x4}) ↓* (HIIT _{10x1}) ↔ (CONT)

Legend: HIIT – high-intensity interval training; MICT – moderate continuous training; CONT – control group; HIITfast – high-intensity interval training in fasted state; HIITfed – HIIT in fed state; REHIIT – reduced – exertion high intensity interval training; WG – walking group; JG – jogging group; HRmax – maximal heart rate; Wmax – maximum power output; VO2peak – peak oxygen uptake; HIIT4x4 – high volume high intensity interval training; HIIT10x1 – low volume high-intensity interval training; HRR – heart rate reserve; PPG – postprandial glucose levels; ↑* – significant improvement; ↓* – significant reduction; ↔ – unchanged; NA – non-applicable

that sex is a significant predictor, with greater improvements typically observed in male participants (27). This difference may be explained by physiological mechanisms, such as increased insulin sensitivity (29) and post-exercise glucose metabolism (30) in males compared to females. Finally, when considering individual studies that measured 24-h mean glucose levels and included both male and female participants, general improvements were observed across genders. Thus, although several individual studies in this review have reported overall improvements in 24-h mean glucose levels across both male and female participants, none have specifically stratified these outcomes by sex or thoroughly examined sex-specific physiological responses. This lack of targeted analysis creates a gap in the literature, hindering a comprehensive understanding of the underlying mechanisms that may account for sex-specific differences in the response to exercise. Finally, participants with higher baseline glucose values tend to show more substantial improvements in 24-h mean glucose levels, while participants with well-controlled conditions may experience minimal or no benefit from exercise training (18). Postprandial glucose levels constitute an independent risk factor for cardiovascular disease (31). Notably, impaired postprandial glucose regulation has been linked to elevated oxidative stress (32), upregulated expression of proinflammatory markers (33), and endothelial dysfunction (8). Therefore, our review demonstrated a reduction in postprandial glucose following exercise interventions when compared to the control group in individuals with T2DM. These findings suggest that exercise, irrespective of modality, is an effective strategy for improving postprandial glycemic control in T2DM patients. Despite a limited number of individual studies exploring the effects of exercise on postprandial glucose in this population, our results are consistent with previous research (26) that indicates the beneficial impact of exercise on postprandial glucose regulation. However, postprandial glucose levels are influenced by numerous factors, with timing being one of the most crucial. It has been demonstrated that engaging in an exercise session following a meal is superior in reducing postprandial glucose levels

compared to exercising before a meal. Another significant factor is the duration of the activity. Finally, postprandial glucose levels largely depend on the type of the activity performed. Specifically, it was demonstrated that aerobic exercises such as walking, running, or cycling lead to more pronounced changes in this parameter due to the predominant engagement of lower body musculature. This suggests that activating the upper body muscles offers little to no benefit in terms of improving postprandial glucose levels (34).

Time spent in hyperglycemia is associated with increased risk of all-cause and cardiovascular diseases (CVD's) mortality among patients with T2D (35). Previous research (36, 37) has highlighted that despite pharmacological therapy, a significant proportion of individuals with T2DM spend considerable time in hyperglycemia, underscoring the need for additional non-pharmacological strategies to improve glycemic control. The analysis of a limited number of studies ($n = 4$) demonstrated that exercise interventions are effective in reducing the time spent in hyperglycemia, with HIIT showing a greater impact compared to other modalities. This finding is clinically significant since there are concerns that HIIT may initially exacerbate hyperglycemia due to the secretion of counter-regulatory hormones. However, this transient hyperglycemic response is a normal physiological reaction to high-intensity exercise and is typically followed by the stabilization and gradual decline of blood glucose levels shortly after the HIIT session. Moreover, this transient response to HIIT may help prevent the occurrence of hypoglycemia which is frequently observed following MICT (38) and represents one of the primary perceived barriers to exercise among individuals with T2DM (39). Thus, despite initial concerns, HIIT may offer a safer alternative for managing glycemic fluctuations in individuals with T2DM. This systematic review is not without limitations. Firstly, the limited number of studies evaluating the impact of different exercise modalities restricts the generalizability of findings to the broader population with T2DM. Moreover, the lack of studies examining the potential role of resistance training as

effective training as effective further limits the scope of this review, as resistance training is known to independently influence long-term glycemic control and other cardiometabolic outcomes. Another notable limitation is the presence of heterogeneity in the experimental protocols such as variations in exercise type, intensity, duration, and methods of intensity quantification which complicates the direct comparison and synthesis of results.

In conclusion, both MICT and HIIT demonstrated acute reductions in mean 24-hour glycemic concentrations, postprandial glucose excursions, and the percentage of time spent in hyperglycemia. These findings suggest that both modalities are effective non-pharmacological strategies for optimizing glycemic control in patients T2DM. Future research should focus on examining additional indices of glycemic control, including glycemic variability and time-in-range (TIR). Moreover, studies should explore the underlying physiological mechanisms contributing to these acute responses, particularly insulin sensitivity and β -cell function, to better understand the role of exercise in the comprehensive management of T2DM.

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Competing Interest

The authors declare no relevant conflicts of interest.

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