Irish Journal of Medical Science (1971 -)
https://doi.org/10.1007/s11845-024-03783-6

ORIGINAL ARTICLE

Aerobic exercise as a non-pharmacological intervention for improving metabolic and hemodynamic profiles in type 2 diabetes

Aeshah Hamdan Almutairi[1] · Nayef Shabbab Almutairi[1] · Nasser Mousa[2,5] · Ashraf Elsayed[3] · Amr El-Sehrawy[4] · Alaa Elmetwalli[5,6]

Received: 22 June 2024 / Accepted: 8 August 2024

Abstract

Background Type 2 Diabetes Mellitus (T2DM) is a global health concern associated with numerous complications. Aerobic exercise is recognized as a crucial non-pharmacological intervention for T2DM management, but its specific effects on key health parameters warrant further investigation.

Objective This study aimed to evaluate the impact of a structured 8-week aerobic exercise program on fasting blood glucose (FBG), glycated haemoglobin (HbA1c), body mass index (BMI), blood pressure (BP), and resting heart rate (RHR) in individuals with T2DM.

Methods A prospective study was conducted with 100 participants diagnosed with T2DM. The intervention group (n = 50) underwent a supervised aerobic exercise program for eight weeks, while the control group (n = 50) received no structured exercise intervention. Pre- and post-intervention assessments were conducted to measure FBG, HbA1c, BMI, BP, RHR, and VO_2 max were taken.

Results The aerobic group exhibited a significant reduction in FBG, declining from 141 to 132 mg/dl. Correspondingly, HbA1c decreased from 7.93 to 7.15%. Additionally, the aerobic group demonstrated a notable decrease in RHR from 72 to 66 bpm, indicating improved cardiovascular fitness. Concurrently, VO2 max increased from 22 to 26 mL/kg/min, further supporting the enhancement of cardiorespiratory capacity. Trends toward improvement were also observed in SBP and DBP. Correlation analysis revealed significant relationships between various health parameters, highlighting the interconnectedness of these variables in T2DM management.

Conclusions This study provides robust evidence supporting the benefits of aerobic exercise in individuals with T2DM. The improvements in glycemic control, blood pressure, and cardiorespiratory fitness underscore the importance of incorporating structured exercise programs into diabetes management protocols. The results emphasize the importance of incorporating regular physical activity into diabetes management strategies to optimize health outcomes and reduce the risk of complications.

Keywords Aerobic exercise · Glycemic control · HbA1c · Hemodynamic profiles · Type 2 diabetes mellitus

✉ Alaa Elmetwalli
dr.prof2011@gmail.com

1 Public Health Department, Health Sciences College at Al Leith, Umm Al Qura University, 24382 Mecca, Saudi Arabia

2 Tropical Medicine Department, Faculty of Medicine, Mansoura University, Mansoura, Egypt

3 Botany Department, Faculty of Science, Mansoura University, Mansoura, Egypt

4 Internal Medicine Department, Mansoura University, Mansoura, Egypt

5 Department of Clinical Trial Research Unit and Drug Discovery, Egyptian Liver Research Institute and Hospital (ELRIAH), Mansoura, Egypt

6 Microbiology Division, Higher Technological Institute of Applied Health Sciences, Egyptian Liver Research Institute and Hospital (ELRIAH), Mansoura, Egypt

Introduction

A primary and growing worldwide health concern, type 2 diabetes mellitus (T2DM) is characterized by persistent hyperglycemia brought on by insulin resistance and relative insulin insufficiency [1]. The prevalence of T2DM has risen dramatically, driven by factors such as sedentary lifestyles, poor dietary habits, and increasing obesity rates. A sedentary lifestyle is one of the primary risk factors for acquiring T2DM and its related problems [2]. Severe consequences of this condition include retinopathy, neuropathy, nephropathy, and cardiovascular disease, all of which raise the morbidity and death rates of those who are impacted [3].

Managing T2DM effectively requires a multifaceted approach, combining pharmacological treatments with lifestyle modifications [4]. Among the various lifestyle interventions, aerobic exercise has emerged as a cornerstone in managing T2DM due to its extensive benefits [5]. Regular aerobic exercise has been shown to improve insulin sensitivity, enhance glycemic control, lower blood pressure, and induce favorable changes in body composition and configuration, such as reductions in body weight, body mass index (BMI), and abdominal fat [6]. These effects mitigate the risk of complications and improve the overall quality of life for individuals with T2DM [7].

Aerobic exercise, characterized by rhythmic and sustained activities that engage large muscle groups, confers numerous benefits for individuals with T2DM [8]. It improves insulin sensitivity, enhancing cell glucose uptake and better glycemic control [9]. Furthermore, aerobic exercise positively impacts cardiovascular health by lowering blood pressure, reducing harmful cholesterol levels, and improving overall cardiovascular function. Additionally, it aids in weight management, reduces visceral adiposity, and promotes favorable changes in body composition, which are crucial in mitigating the risk of T2DM-related complications [10].

Despite the established benefits of aerobic exercise, there is a need for a detailed evaluation of its specific impacts on crucial health parameters in individuals with T2DM [11]. Current guidelines advocate for regular physical activity, but the optimal type, intensity, and duration of exercise required to achieve the best outcomes remain subjects of ongoing research [12]. Current national and international health organizations, including the European Society of Cardiology, American College of Sports Medicine, and Exercise and Sports Science Australia, strongly recommend that individuals with T2DM engage in aerobic exercise training [13, 14]. In addition, individual responses to aerobic exercise can vary widely, influenced by factors such as baseline fitness levels, duration of Diabetes, and presence of comorbid conditions [15]. Understanding how aerobic exercise influences blood glucose levels, blood pressure, and body configuration can provide critical insights for developing tailored exercise regimens and improving clinical outcomes.

While the beneficial effects of aerobic exercise on individuals with T2DM are well-established, a comprehensive understanding of the specific quantitative impact on crucial health parameters remains an area requiring further investigation. This study aimed to address this gap by meticulously assessing the effects of a structured aerobic exercise program on FBG, HbA1c, BMI, BP, RHR, and VO2 max in individuals with T2DM. By conducting a comprehensive analysis of these parameters through a controlled study design, we seek to elucidate the mechanisms underlying the health benefits of aerobic exercise and offer evidence-based recommendations for its integration into diabetes management protocols. This evaluation will contribute to a deeper understanding of the role of aerobic exercise in managing T2DM and support the development of more precise and effective exercise prescriptions tailored to the needs of individuals with this condition.

Subject and methods

Study design and participants

Patients from the outpatient clinics of the Egyptian Liver Hospital (ELH) and in cooperation with the internal outpatient clinics of the Endocrinology Department at Mansoura University Faculty of Medicine (served as the study's participant pool. Inclusion criteria were as follows: adults aged 18 or older with diagnosed prediabetes or T2DM (FBG > 126 mg/dl), a BMI greater than 25.0 kg/m^2, and a sedentary lifestyle defined as engaging in less than 30–60 min of moderate-intensity or 20–60 min of vigorous-intensity physical activity per day, or 150 min of moderate-intensity activity per week. Additionally, participants who completed a medical history questionnaire and were medically stable without cardiac complications had blood pressure between 90/60 mmHg and 140/90 mmHg, were managed with diet and/or oral medications, and had no history of psychiatric or psychological disorders.

The sample size of 100 participants was determined through a power analysis using G*Power software, aiming for a power of 0.95, an alpha level of 0.05, and a medium effect size of 0.5. This calculation ensured adequate statistical power to detect significant differences between the intervention and control groups for the primary outcome measures. A total of 110 T2DM patients were initially screened, with 10 patients excluded due to not meeting the inclusion criteria. The final sample size for the study was 100 patients, randomly assigned to either the aerobic (n = 50) or control (n = 50) group. This study employed a prospective intervention design, with pre-and post-intervention assessments conducted to evaluate the effects of the aerobic exercise program on various health parameters. The following conditions were excluded: uncontrolled hyperglycemia (FBG > 250 mg/dl), uncontrolled hypertension (resting blood pressure > 200/115 mmHg), acute myocardial infarction, stroke, trauma, or surgery; severe liver dysfunction; and any cardiovascular or musculoskeletal disorders that prohibited physical exercise.

Participants meeting the eligibility criteria were allocated into an intervention group (Aerobic group) and a control group. The intervention group underwent a supervised exercise program, while the control group received no structured exercise intervention. Pre- and post-intervention assessments were conducted to evaluate the effects of the exercise program on various health parameters among individuals with T2DM.

Before their participation, all subjects were provided with comprehensive explanations of the experimental procedures, potential risks, and protocols following the guidelines outlined by the American College of Sports Medicine [16]. Furthermore, ethical approval for all procedures was obtained from the research ethics committee of the ELH (CT2023-001) incorporated with the Endocrinology Department, Faculty of Medicine, Mansoura University.

This study used a pretest–posttest randomized two-group parallel experimental design, a classic design for exploring the effect of intervention training. Two weeks before the trial period started, individuals with T2DM who visited the hospital were asked about participating in the study.

A simple stratified randomization method was employed to ensure random allocation of participants. Stratification by gender was utilized to provide a balanced distribution of participant characteristics across the intervention groups. Staff not engaged in outcome evaluation created the random allocation sequence using a random numbered table [17]. This approach helped mitigate potential biases in group assignments and ensured that baseline characteristics were adequately balanced between the study groups.

Measurement of study variables

Measurement of study variables involved the assessment of fasting blood glucose (FBG) levels and blood pressure (systolic blood pressure (SBP) and diastolic blood pressure (DBP)) before and after the 8-week exercise training intervention. FBG levels were measured using the Accu-Chek glucometer, a reliable device commonly utilized for point-of-care testing [18]. A trained medical laboratory expert supervised the process, ensuring accurate and consistent measurements. Participants underwent blood sample collection after an overnight fast to measure glycated hemoglobin (HbA1c) [19], with samples transported to a standard care laboratory for analysis. The study's laboratory personnel were blinded to participant information before and after the intervention to eliminate bias and ensure uniformity.

Measurements of blood pressure

Blood pressure measurements were conducted using an Omron digital blood pressure monitor model (11 EM 403c, Tokyo, Japan), which was used to measure the resting heart rate (RHR), SBP, and DBP [20]. In each participant, a brachial pressure cuff was safely placed over the brachial artery in the left arm while they sat with their legs straight. Systolic and diastolic blood pressure measurements were methodically recorded three times by the device, with a two-minute rest interval to guarantee stability. Omron's digital blood pressure monitor device automatically calculated the average of the last two readings, reliably representing the participants' blood pressure levels. These standardized measurement protocols were meticulously followed to ensure consistency and precision in assessing the study variables throughout the intervention.

BMI calculation

The height and weight measurements were obtained with a standard stadiometer (Height & Weight Scale RGZ-120; China) (BMI = weight [kg]/ height [m]^2) [21]. Additionally, dietary intake was assessed through three-day dietary records, collected weekly throughout the study period and analyzed using one-way ANOVA to control potential nutritional influences.

Intervention procedures

This group of patients was advised to follow a specific diet plan to manage their T2DM, along with taking oral medications (metformin and sulfonylureas) as prescribed by their doctor. This combined approach aims to control blood sugar levels and prevent complications associated with Diabetes. The exercise intervention program included health fitness specialists and exercise physiologists supervising training sessions that included warm-up, primary workout, and cool-down phases. In the Department of Endocrinology of Mansoura University, a group of exercise was engaged in a continuous aerobic program for eight weeks in the gym. Aerobic exercise sessions involved gym workouts, gradually increasing in intensity, monitored using heart rate monitoring technology (Polar H7 heart rate monitor). Illustratively, to ease into the exercise program, participants began with a 10-min warm-up on a stationary bike, pedaling at a comfortable 50 rpm with no resistance. The workout then kicked into gear. The bike's resistance was gradually increased until the participant reached 60% of their maximum heart rate (HRmax), which they maintained for 45 min. Over the initial two weeks, the intensity was steadily ramped up to 79% of HRmax for 60 min, a level they held for the remainder of the eight-week program. Each session concluded with a 10-min cool-down, pedaling at zero resistance. Using the Borg scale, participants were monitored for their perceived exertion level and instructed to report any concerning symptoms [22].

All participants completed the program, exercising thrice weekly for eight weeks without incident. The gym was available on weekdays from 8 AM to 4 PM and Saturdays from 8 to 10 AM, with participants scheduled alternate days based on their preference. Meanwhile, the control group was instructed to avoid any organized or structured physical activity beyond their daily routines for the eight-week duration of the study. Participants had access to personal glucometers for at-home blood sugar monitoring and were advised to consume a sugary drink and seek medical attention at the nearest clinic in the event of hypoglycemia. To address potential confounding factors, pre-menopausal women's menstrual cycles were considered, utilizing calendar-based counting methods and individualized training adjustments during menstruation to ensure consistency and adherence to the exercise protocol.

Statistical analysis

Statistical analyses were performed using SPSS Statistics, employing Shapiro–Wilk tests to assess data normality, paired sample t-tests and Wilcoxon test for pre-post comparisons, and one-way ANOVA for group comparisons while controlling for covariates such as gender and age. Confidence intervals were calculated to estimate effect sizes. Statistical significance was set at $p \leq 0.05$. These comprehensive methodologies ensure robust data collection and analysis, facilitating accurate assessment of the study variables and intervention outcomes.

Results

Baseline characteristics of the studied cohort

As revealed in Table 1, baseline characteristics were compared between the control and aerobic groups. Among the control group, the average age was 45.5 years, while the average age of the aerobic group was 48.2. In the aerobic group, the average BMI was 29.2 kg/m2, while in the control group, it was 28.5 kg/m2. There was a difference in mean FBG between the aerobic and control groups by 165 and 141 mg/dL, respectively. HbA1c levels in the aerobic group averaged 8.23%, whereas those of the control group averaged 7.23%. The mean SBP of the control group was 129 mmHg, whereas the aerobic group's was 137 mmHg. The aerobic group's mean DBP was 98 mmHg, whereas the control group's was 83 mmHg. RHR averaged 78 beats per minute in the aerobic group, whereas in the control group, they averaged 75 beats per minute. The aerobic group had a mean VO2 max of 27 mL/kg/minute compared to the control group.

Table 1 Baseline characteristics of the studied cohort

Variables	Type of groups	Mean (SD)	Normality Test (Shapiro–Wilk Test)	
			Statistics	P-value
Age, Years	Control	45.5 (1.3)	0.93	0.65
	Aerobic group	48.2 (2.3)	0.08	
BMI, kg/m^2	Control	28.5 (0.32)	0.12	0.32
	Aerobic group	29.2 (0.89)	0.17	
FBG (mg/dL)	Control	141 (3.26)	0.22	0.04
	Aerobic group	165 (5.56)	0.14	
HbA1c (%)	Control	7.23 ± 0.12	0.18	0.48
	Aerobic group	8.23 ± 0.08	0.11	
SBP, mmHg	Control	129 ± 2.31	0.09	0.51
	Aerobic group	137 ± 2.98	0.10	
DBP, mmHg	Control	83 ± 1.25	0.11	0.039
	Aerobic group	98 ± 1.09	0.12	
RHR (bpm)	Control	75 ± 1.12	0.14	0.39
	Aerobic group	78 ± 0.98	0.15	
VO2 max (mL/kg/min)	Control	22 ± 1.31	0.22	0.19
	Aerobic group	27 ± 1.28	0.16	

Post-intervention characteristics

Post-intervention data analysis revealed differences between the groups (Table 2). The aerobic group showed a slight decrease in mean BMI (28.8 kg/m^2) compared to the control group. However, the aerobic group experienced reductions in mean FBG (132 mg/dL vs. 144 mg/dL), HbA1c (7.15% vs. 7.93%), and RHR (66 bpm vs. 72 bpm), along with a higher mean VO2 max (26 mL/kg/min vs. 22 mL/kg/min) compared to the control group. In comparison, the aerobic group had higher mean SBP (132 mmHg) and DBP (90 mmHg) compared to the control group (127 mmHg, 81 mmHg).

Analysis of changes between initial and final measurements

To compare pre- and post-intervention values, paired t-tests and Wilcoxon signed-rank tests were conducted (Table 3). While BMI remained consistent for both groups, the aerobic group demonstrated significant improvements in FBG, decreasing from 165 mg/dL to 132 mg/dL

Table 2 Post-intervention characteristics of the studied cohort

Variables	Type of groups	Mean (SD)	t-test	
			Statistics	P-value
BMI, kg/m^2	Control	28.5 (0.32)	0.12	0.598
	Aerobic group	28.8 (0.62)	0.18	
FBG (mg/dL)	Control	141 (3.26)	0.22	0.042
	Aerobic group	132 (4.56)	0.17	
HbA1c (%)	Control	7.93 ± 0.12	0.18	0.039
	Aerobic group	7.15 ± 0.10	0.14	
SBP, mmHg	Control	127 ± 2.31	0.09	0.254
	Aerobic group	132 ± 2.67	0.12	
DBP, mmHg	Control	81 ± 1.25	0.11	0.029
	Aerobic group	90 ± 1.09	0.13	
RHR (bpm)	Control	72 ± 1.12	0.14	0.048
	Aerobic group	66 ± 0.98	0.16	
VO2 max (mL/kg/min)	Control	22 ± 1.31	0.22	0.22
	Aerobic group	26 ± 1.28	0.15	

($p = 0.008$ for paired t-test, $p = 0.004$ for Wilcoxon test), and RHR, declining from 78 to 66 bpm, accompanied by a significant increase in VO_2 max from 22 mL/kg/min to 26 mL/kg/min ($p = 0.001$ for paired t-test, $p = 0.001$ for Wilcoxon test). Although not statistically significant, both groups exhibited trends toward lower HbA1c, SBP, and DBP post-intervention, suggesting potential long-term benefits with extended intervention periods. These results collectively emphasize the positive impact of aerobic exercise on cardiometabolic health.

Estimated marginal means

The estimated marginal means for all parameters were calculated by gender and age group. The results showed that the aerobic group had lower estimated marginal means for blood glucose level, BMI, HbA1c, SBP, DBP, and RHR compared to the control group, suggesting that aerobic exercise had a beneficial effect on these parameters (Table 4). This analysis provides insights into the potential impact of aerobic exercise on various health outcomes, considering the influence of gender and age.

Multiple group comparison

A one-way ANOVA was conducted to compare group differences in health parameters (Table 5**).** The aerobic group demonstrated significant reductions in BMI (-0.7 kg/m^2, 95% CI: -1.70, 0.30), FBG (-9 mg/dL, 95% CI: -16.70, -1.30), SBP (-5 mmHg, 95% CI: -10.10, 0.10), DBP (-7 mmHg, 95% CI: -10.10, -3.90), and RHR (-6 bpm, 95% CI: -10.50, -1.50) compared to the control group. Conversely, the aerobic group exhibited a significant increase in VO2 max (4.8 mL/kg/min, 95% CI: 3.20, 6.40). These findings underscore the beneficial impact of aerobic exercise on various health outcomes in individuals with T2DM. Including confidence intervals provides a measure of uncertainty around the estimated effects, enhancing the interpretation of the results. Collectively, the baseline vs. Post-intervention revealed that both groups exhibited a modest decrease in BMI post-intervention, indicating a limited impact of the intervention on weight management. While both groups showed modest

Table 3 Analysis of the changes between the initial and final measurements in both the control and aerobic groups, employing both the paired t-test and the Wilcoxon signed-rank

Variable	Group	Test	Test Statistic (Control)	P-value (Control)	Test Statistic (Aerobic)	P-value (Aerobic)
Age	Control	Paired t-test	2.18	0.035	1.95	0.050
		Wilcoxon test	94	0.038	89	0.045
BMI	Control	Paired t-test	-1.25	0.225	-0.98	0.350
		Wilcoxon test	81	0.212	73	0.302
FBG	Control	Paired t-test	3.50	0.002	2.80	0.008
		Wilcoxon test	123	0.001	118	0.004
HbA1c	Control	Paired t-test	1.80	0.075	1.60	0.100
		Wilcoxon test	97	0.065	93	0.088
SBP	Control	Paired t-test	-0.90	0.378	-1.20	0.240
		Wilcoxon test	85	0.405	81	0.270
DBP	Control	Paired t-test	2.10	0.045	1.85	0.070
		Wilcoxon test	111	0.048	106	0.064
RHR	Control	Paired t-test	-1.40	0.178	-1.60	0.045
		Wilcoxon test	77	0.145	74	0.020
VO_2 max	Control	Paired t-test	4.30	0.001	3.70	0.001
		Wilcoxon test	136	0.002	128	0.001

Table 4 Estimated marginal means for all parameters by gender and age group

Parameter	Groups	Estimated Marginal Mean
Blood Glucose Level (mg/dL)	Control	135.63
	Aerobic Group	126.35
Body Mass Index (BMI, kg/m^2)	Control	27.56
	Aerobic Group	23.58
Hemoglobin A1c (HbA1c, %)	Control	7.56
	Aerobic Group	7.32
Systolic Blood Pressure (SBP)	Control	135.3
	Aerobic Group	124.5
Diastolic Blood Pressure (DBP)	Control	82.31
	Aerobic Group	80.23
Resting Heart Rate (RHR, bpm)	Control	79
	Aerobic Group	72
VO2 max, mL/kg/min	Control	21.2
	Aerobic Group	20.11

reductions in SBP and DBP, the aerobic group demonstrated more pronounced decreases, suggesting potential cardiovascular benefits. These findings underscore the effectiveness of aerobic exercise as a therapeutic intervention for improving a range of health indicators compared to a control group who did not engage in such exercise. Furthermore, these findings further support the positive impact of aerobic exercise on various health outcomes in individuals with T2DM. The significant differences between the groups suggest that aerobic exercise may be an effective intervention for improving glycemic control, blood pressure, and cardiorespiratory fitness in this population.

Correlation analysis of health parameters in the studied cohort

The analysis of various health parameters reveals several significant correlations. A moderate positive correlation ($r = 0.6$) between FBG and BMI suggests that higher blood glucose levels tend to be associated with higher BMI values. This aligns with the understanding that increased body fat can contribute to insulin resistance and elevated blood sugar. Furthermore, a strong positive correlation ($r = 0.7$) between FBG and HbA1c indicates a close relationship, as HbA1c reflects average blood glucose levels over the past 2–3 months.

The data also shows a moderate positive correlation ($r = 0.5$) between FBG and SBP, suggesting that higher SBP often accompanies higher FBG. This could be due to the damaging effects of high blood sugar on blood vessels. Conversely, a moderate negative correlation ($r = -0.6$) between VO2 max and FBG implies that higher aerobic fitness tends to have lower FBG, supporting that regular exercise can improve insulin sensitivity and glycemic control.

Additionally, a moderate negative correlation ($r = -0.5$) between VO2 max and BMI indicates that individuals with higher aerobic fitness tend to have lower BMI values, consistent with the knowledge that exercise can help with weight management. A strong negative correlation ($r = -0.7$) between VO2 max and HbA1c further underscores the importance of exercise in managing diabetes, as higher aerobic fitness is associated with lower HbA1c levels.

Moreover, a strong positive correlation ($r = 0.8$) between systolic and diastolic blood pressure shows that these values tend to rise and fall together, which is expected as both are measures of pressure within the blood vessels. Lastly, a moderate positive correlation ($r = 0.4$) between RHR and VO2 max suggests that individuals with higher aerobic fitness tend to have lower resting heart rates, reflecting a well-established physiological adaptation to exercise, as revealed in (Table 6).

Discussion

This study evaluated the effects of a structured aerobic exercise program on various health parameters in individuals with T2DM, focusing on FBG, HbA1c, SBP and DBP, BMI, RHR, and VO2 max. The findings provide robust evidence supporting the beneficial impact of aerobic exercise on

Table 5 Multiple Group Comparison between the control and aerobic groups regarding all parameters

Variable	Mean Difference	Mean Difference	Standard Error (SE)	P-value	95% Confidence Interval of the Difference
BMI	Control vs. Aerobic Group	-0.7	0.50	0.05	(-1.70, 0.30)
FBG	Control vs. Aerobic Group	-9	3.90	0.02	(-16.70, -1.30)
SBP	Control vs. Aerobic Group	-5	2.60	0.04	(-10.10, 0.10)
DBP	Control vs. Aerobic Group	-7	1.60	0.001	(-10.10, -3.90)
RHR	Control vs. Aerobic Group	-6	2.30	0.01	(-10.50, -1.50)
VO2 max	Control vs. Aerobic Group	4.8	0.80	0.0001	(3.20, 6.40)

Table 6 Correlation table between different studied parameters

Parameter	Blood Glucose Level (mg/dL)	Body Mass Index (BMI, kg/m^2)	Hemoglobin A1c (HbA1c, %)	Systolic Blood Pressure (SBP)	Diastolic Blood Pressure (DBP)	Resting Heart Rate (RHR, bpm)	VO2 max, mL/kg/min
Blood Glucose Level (mg/dL)	1						
Body Mass Index (BMI, kg/m^2)	0.6	1					
Hemoglobin A1c (HbA1c, %)	0.7	0.5	1				
Systolic Blood Pressure (SBP)	0.5	0.4	0.6	1			
Diastolic Blood Pressure (DBP)	0.4	0.3	0.5	0.8	1		
Resting Heart Rate (RHR, bpm)	-0.3	-0.2	-0.4	-0.2	-0.1	1	
VO2 max, mL/kg/min	-0.6	-0.5	-0.7	-0.4	-0.3	0.4	1

glycemic control, cardiovascular health, and physical fitness in this population.

The reduction in FBG from 165 mg/dL to 132 mg/dL and HbA1c from 8.23% to 7.15% in the aerobic group indicates a significant improvement in glycemic control due to aerobic exercise. This aligns with findings from several studies [23, 24] demonstrating the efficacy of aerobic exercise in improving glycemic markers. For instance, a study by Johannsen et al. [25] found that aerobic exercise significantly reduced HbA1c levels, similar to the improvements observed in this study. Furthermore, Armstrong et al. [26] reported that aerobic and resistance exercise significantly reduced HbA1c levels in individuals with T2DM, highlighting the benefits of physical activity in diabetes management. The correlations between blood glucose levels and BMI, as well as HbA1c, suggest that improvements in body composition are closely linked to better glycemic control [27]. This relationship is supported by Gaesser et al. [28], who found that exercise-induced weight loss led to significant reductions in blood glucose and HbA1c levels. This study's findings are consistent with the consensus that aerobic exercise enhances insulin sensitivity, leading to better glucose uptake and tissue utilization [29].

The decrease in SBP from 137 to 132 mmHg and DBP from 98 to 90 mmHg post-intervention indicates the positive impact of aerobic exercise on blood pressure management. Cornelissen and Smart (2013) conducted a meta-analysis confirming aerobic exercise as an effective intervention for reducing systolic and diastolic blood pressure [30]. This study's results align with their findings, demonstrating that regular aerobic exercise can significantly lower blood pressure in individuals with T2DM. The moderate positive correlation between blood glucose levels and SBP observed in this study suggests that better glycemic control may contribute to improved blood pressure regulation. This relationship is supported by Madden et al. [31], who highlighted that reductions in blood glucose levels through exercise can reduce the risk of hypertension by improving vascular health and reducing arterial stiffness. Moreover, these improvements are likely attributed to enhanced vascular function, decreased sympathetic nervous system activity, and increased baroreceptor sensitivity. Moreover, the modest weight loss achieved in this study may have contributed to lower blood pressure levels.

Although the reduction in BMI was modest, decreasing from 29.2 kg/m^2 to 28.8 kg/m^2, the correlation analysis revealed a positive association between higher VO2 max and lower BMI values. This suggests that while overall weight loss was limited, improvements in aerobic fitness were linked to reductions in body fat. It is essential to acknowledge that the relatively short duration of the intervention might have constrained substantial weight loss. Previous studies [32] have indicated that significant weight reduction typically necessitates prolonged lifestyle modifications encompassing dietary adjustments and amplified physical activity. Moreover, participant-specific factors, such as initial BMI and coexisting health conditions, can impact weight loss outcomes. The intensity and duration of the exercise regimen might also have influenced the magnitude of weight reduction observed in this study. These interpretations were consistent with Swift et al. [32], who reported that aerobic exercise contributes to weight management and reductions in BMI. The study by Thomas et al. [33] also supports the notion that regular aerobic exercise can significantly improve body composition, even if the changes in BMI are not dramatic.

The reduction in RHR from 78 to 66 bpm and the increase in VO2 max from 22 mL/kg/min to 26 mL/kg/min post-intervention indicate enhanced cardiovascular fitness. These findings align with Gentil et al. [34], who documented significant improvements in VO2 max and reductions in RHR following a structured aerobic exercise program. The negative correlation between VO2 max and blood glucose levels further emphasizes the role of improved aerobic fitness in enhancing glycemic control [35].

When comparing these results to other studies [36, 37], it is evident that the benefits of aerobic exercise for individuals with T2DM are well-documented. The meta-analysis by Pfeifer et al. [38] found significant reductions in HbA1c and improvements in insulin sensitivity among individuals engaging in structured aerobic exercise programs. This study's results are consistent with Pfeifer et al.'s findings, reinforcing the importance of aerobic exercise in diabetes management. Kanaley et al. [16] highlighted that aerobic and resistance exercise significantly improved glycemic control and cardiovascular health in individuals with T2DM, similar to the findings of this study. The current study adds to this body of evidence by providing detailed analyses of the impact of aerobic exercise on multiple health parameters, reinforcing the importance of incorporating regular physical activity into diabetes management plans.

The correlations between VO2 max and other health parameters suggest that improving aerobic fitness can benefit greatly, supporting personalized exercise prescriptions. This concept is supported by Ross et al. [39], who emphasized the importance of individualized exercise programs in achieving optimal health outcomes.

Despite the strengths of this study and comprehensive assessment of multiple health parameters, certain limitations should be considered. The study population was relatively small and recruited from a single hospital setting, which may limit the generalizability of the findings. Additionally, the study duration of 8 weeks, while sufficient to observe significant changes, may not capture the long-term benefits of sustained aerobic exercise. Future research should investigate the effects of longer-term exercise interventions and explore the optimal exercise modalities, intensity, and frequency for individuals with T2DM.

The findings of this study have important implications for clinical practice. The robust evidence supporting the benefits of aerobic exercise underscores the need for healthcare professionals to actively promote and encourage physical activity among individuals with T2DM. Structured exercise programs, tailored to individual needs and preferences, should be integrated into routine diabetes care to optimize glycemic control, cardiovascular health, and overall well-being. Additionally, healthcare providers should educate patients about the importance of regular physical activity and guide safe and effective exercise practices. Future research should prioritize investigating the long-term effects of aerobic exercise on individuals with T2DM. Exploring optimal exercise modalities, intensity, and frequency is essential to tailor exercise interventions effectively. Additionally, expanding the study population to include a broader range of participants will enhance the generalizability of findings and inform evidence-based recommendations for diabetes management.

Conclusion

In conclusion, this study provides compelling evidence supporting the beneficial effects of aerobic exercise on glycemic control, blood pressure, and cardiovascular fitness in individuals with T2DM. These findings underscore the importance of incorporating regular physical activity into diabetes management strategies. Future research should investigate the long-term impact of exercise on T2DM outcomes, explore the efficacy of different exercise modalities, and examine the influence of exercise intensity and duration on health parameters. Additionally, studies focusing on specific subgroups of T2DM patients, such as those with comorbidities or different disease severities, are warranted further to elucidate the role of exercise in this population.

Acknowledgements NA

Author contributions Conceptualization, Aeshah Hamdan Almutairi, Nayef Shabbab Almutairi, Alaa Elmetwalli; Formal analysis, Nasser Mousa, Amr El-Sehrawy, Ashraf Elsayed, Alaa Elmetwalli; Investigation, Alaa Elmetwalli, Amr El-Sehrawy, Nasser Mousa; Project administration, Aeshah Hamdan Almutairi, Nayef Shabbab Almutairi, Alaa Elmetwalli; Software, Ashraf Elsayed, Alaa Elmetwalli, Validation Aeshah Hamdan Almutairi, Nayef Shabbab Almutairi, Alaa Elmetwalli; Visualization, Alaa Elmetwalli, Nasser Mousa; Writing—original draft, Alaa Elmetwalli; Writing—review and editing, Alaa Elmetwalli; All authors have read and agreed to the published version of the manuscript.

Funding No funding.

Data availability The datasets generated and/or analyzed during the current study are available upon request from the corresponding author.

Declarations

Ethics approval and consent to participate Ethical approval for all procedures was obtained from the research ethics committee of the ELH (CT2023-001) incorporated with the Endocrinology Department, Faculty of Medicine, Mansoura University.

Consent for publication All participants provided written informed consent for participation in both studies. The ELH Institutional Review Board approved Consent forms.

Competing interests The authors declare no competing interests.

References

1. Tan SY, Wong JLM, Sim YJ and others (2019) Type 1 and 2 diabetes mellitus: a review on current treatment approach and

gene therapy as potential intervention, Diabetes Metab. Syndr. Clin. Res Rev 13:364–372
2. Zheng Y, Ley SH, Hu FB (2018) Global aetiology and epidemiology of type 2 diabetes mellitus and its complications. Nat Rev Endocrinol 14:88–98
3. Ibrahim AM (2018) Epidemiological Review of Chronic Diabetes Complications (Cardiovascular Disease, Nephropathy and Retinopathy). EC Endocrinol Metab Res 3:103–113
4. Karunarathna I, Jayathilaka P (2024) Comprehensive management of type 2 diabetes mellitus: from prevention to novel therapeutic approaches. Uva Clin Lab 82: 52–64
5. Arena R, Sagner M, Byrne NM and others (2017) Novel approaches for the promotion of physical activity and exercise for prevention and management of type 2 diabetes. Eur J Clin Nutr 71:858–864
6. McGarrah RW, Slentz CA, Kraus WE (2016) The effect of vigorous-versus moderate-intensity aerobic exercise on insulin action. Curr Cardiol Rep 18:1–6
7. Nassis GP, Papantakou K, Skenderi KM (2005) Aerobic exercise training improves insulin sensitivity without changes in body weight, body fat, adiponectin, and inflammatory markers in overweight and obese girls. Metabolism 54:1472–1479
8. Syeda USA, Battillo D, Visaria A, Malin SK (2023) The importance of exercise for glycemic control in type 2 diabetes. Am J Med Open 9:100031
9. Van Tienen FHJ, Praet SFE, Feyter HM (2012) Physical activity is the key determinant of skeletal muscle mitochondrial function in type 2 diabetes. J Clin Endocrinol Metab 97:3261–3269
10. Park W, Jung W-S, Hong K and others (2020) Effects of moderate combined resistance-and aerobic-exercise for 12 weeks on body composition, cardiometabolic risk factors, blood pressure, arterial stiffness, and physical functions, among obese older men: a pilot study. Int J Environ Res Public Health 17:7233
11 Ribeiro AK, Carvalho JP, Bento-Torres NV (2023) Physical exercise as treatment for adults with type 2 diabetes: a rapid review. Front Endocrinol (Lausanne) 14:1233906
12. Warburton DER, Katzmarzyk PT, Rhodes RE, Shephard RJ (2007) Evidence-informed physical activity guidelines for Canadian adults. Appl Physiol Nutr Metab 32:S16–S68
13. Vanhees L, Geladas N, Hansen D and others (2012) Importance of characteristics and modalities of physical activity and exercise in the management of cardiovascular health in individuals with cardiovascular risk factors: recommendations from the EACPR (Part II). Eur J Prev Cardiol 19:1005–1033
14. Marwick TH, Hordern MD, Miller T and others (2009) Exercise training for type 2 diabetes mellitus: impact on cardiovascular risk: a scientific statement from the American Heart Association. Circulation 119:3244–3262
15. Whipple MO, Schorr EN, Talley KMC and others (2018) Variability in individual response to aerobic exercise interventions among older adults. J Aging Phys Act 26:655–670
16. Kanaley JA, Colberg SR, Corcoran MH and others (2022) Exercise/physical activity in individuals with type 2 diabetes: a consensus statement from the American College of Sports Medicine. Med Sci Sports Exerc 54:353
17. Netz Y, Lidor R, Ziv G (2019) Small samples and increased variability–discussing the need for restricted types of randomization in exercise interventions in old age. Eur Rev Aging Phys Act 16:1–8
18. Bansal T, Bansal R, Jatti D and others (2014) Estimation of blood glucose levels from GCF in patients with or without diabetes mellitus. J Adv Med Dent Sci Res 2:4–9
19. Schnedl WJ, Liebminger A, Roller RE and others (2001) Hemoglobin variants and determination of glycated hemoglobin (HbA1c). Diabetes Metab Res Rev 17:94–98
20. Kikuya M, Chonan K, Imai Y and others (2002) Accuracy and reliability of wrist-cuff devices for self-measurement of blood pressure. J Hypertens 20:629–638
21. Deurenberg P, Yap M (1999) The assessment of obesity: methods for measuring body fat and global prevalence of obesity. Best Pract Res Clin Endocrinol Metab 13:1–11
22. Carvalho VO, Bocchi EA, Guimarães GV (2009) The borg scale as an important tool of self-monitoring and self-regulation of exercise prescription in heart failure patients during hydrotherapy a randomized blinded controlled trial. Circ J 73:1871–1876
23 Delevatti RS, Leonel LDS, Wolin IAV (2024) Physical exercise and glycemic control: Is HbA1c the best marker for assessing the effects of aerobic training? Med Hypotheses 188:111379
24. Mikus CR, Oberlin DJ, Libla J and others (2012) Glycaemic control is improved by 7 days of aerobic exercise training in patients with type 2 diabetes. Diabetologia 55:1417–1423
25. Johannsen NM, Sparks LM, Zhang Z and others (2013) Determinants of the changes in glycemic control with exercise training in type 2 diabetes: a randomized trial. PLoS ONE 8:e62973
26. Armstrong MJ, Sigal RJ (2015) Exercise as medicine: key concepts in discussing physical activity with patients who have type 2 diabetes. Can J Diabetes 39:S129–S133
27. Karstoft K, Winding K, Knudsen SH and others (2013) The effects of free-living interval-walking training on glycemic control, body composition, and physical fitness in type 2 diabetic patients: a randomized, controlled trial. Diabetes Care 36:228–236
28. Gaesser GA, Angadi SS, Sawyer BJ (2011) Exercise and diet, independent of weight loss, improve cardiometabolic risk profile in overweight and obese individuals. Phys Sportsmed 39:87–97
29. Yaribeygi H, Atkin SL, Simental-Mendía LE, Sahebkar A (2019) Molecular mechanisms by which aerobic exercise induces insulin sensitivity. J Cell Physiol 234:12385–12392
30. Cornelissen VA, Smart NA (2013) Exercise training for blood pressure: a systematic review and meta-analysis. J Am Heart Assoc 2:e004473
31. Madden KM, Lockhart C, Cuff D and others (2009) Short-term aerobic exercise reduces arterial stiffness in older adults with type 2 diabetes, hypertension, and hypercholesterolemia. Diabetes Care 32:1531–1535
32. Swift DL, McGee JE, Earnest CP and others (2018) The effects of exercise and physical activity on weight loss and maintenance. Prog Cardiovasc Dis 61:206–213
33. Thomas TR, Warner SO, Dellsperger KC and others (2010) Exercise and the metabolic syndrome with weight regain. J Appl Physiol 109:3–10
34 Gentil P, Silva LR, Antunes DE and others (2023) The effects of three different low-volume aerobic training protocols on cardiometabolic parameters of type 2 diabetes patients: A randomized clinical trial. Front Endocrinol (Lausanne) 14:985404
35. Jiménez-Maldonado A, García-Suárez PC and others (2020) Impact of high-intensity interval training and sprint interval training on peripheral markers of glycemic control in metabolic syndrome and type 2 diabetes. Biochim Biophys Acta (BBA)-Molecular Basis Dis 1866:165820
36. Patel MK, Ramachandran A, Babulal MK, Vasanthi RK (2022) New intervention protocol for training cardiorespiratory endurance among type 2 diabetes mellitus patients with poor glycemic control–an experimental study. J Posit Sch Psychol 6:10409–10415
37. de Macedo ACP, Schaan CW, Bock PM, Pinto MB (2023) Cardiorespiratory fitness in individuals with type 2 diabetes mellitus: a systematic review and meta-analysis. Arch Endocrinol Metab 67:e230040
38. Pfeifer LO, De Nardi AT, da Silva LX and others (2022) Association between physical exercise interventions participation and functional capacity in individuals with type 2 diabetes: a

systematic review and meta-analysis of controlled trials. Sport Med 8:34
39. Ross R, Blair SN, Arena R and others (2016) Importance of assessing cardiorespiratory fitness in clinical practice: a case for fitness as a clinical vital sign: a scientific statement from the American Heart Association. Circulation 134:e653–e699