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ORIGINAL ARTICLE

A cross-sectional study of optimal exercise combinations for type 2 diabetes

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Abstract

Aim The currently recommended exercise methods for patients with diabetes require strict physical fitness and are not suitable for all diabetic patients. This study aims to explore the best exercise combination for diabetic patients and to provide scientific and practical personalized exercise guidance for diabetic patients.

Subject and methods Basic information about participants was obtained through questionnaires, physical measurements were performed, and fasting blood samples were collected. Polar area diagrams were used to analyze the relationship between different exercise habits and each index. The polar area graph showed the exercise duration with the best expected effect under a particular frequency and intensity. Two-sample Mendelian randomization (MR) was used to test whether there was a direct causal relationship between exercise and diabetes.

Results Polar area diagrams showed that diabetes patients who engaged in moderate- to vigorous-intensity exercise > 60 minutes five times per week had better health indicators. The polar area graph showed that low-intensity exercise once or twice a week required more than 30 minutes to achieve the desired effect. There was no significant difference in any indicators among elderly diabetic patients with different exercise intensities.

Conclusion Moderate- to vigorous-intensity exercise for more than 30 minutes five times a week was the most beneficial combination of exercise for diabetes. Low frequency needs to be matched with longer exercise time to achieve the desired effect at low intensity. The relationship between low frequency and long duration weakened when the exercise intensity increased. The levels of all indicators in elderly diabetic patients were unrelated to exercise intensity.

Keywords Diabetes mellitus · Exercise therapy · Glycemic control · Body composition

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Introduction

Diabetes mellitus (DM) affects more than 440 million people worldwide and is one of the most common metabolic diseases. The Asia-Pacific region has the largest population of people with diabetes, and the prevalence of the disease has increased dramatically in the region in recent decades (Nanditha et al. 2016; Ramachandran et al. 2010). China, with a population of 1.413 billion people, is estimated to have over 120 million people affected by diabetes and currently has the most significant number of people affected by diabetes in any country (Ma 2018).

Exercise is a critical measure in the health management of diabetes. Apart from aiding in weight loss and reducing fat, it can also reduce cardiometabolic-related risk (improve blood lipid and blood pressure), reduce glycosylated hemoglobin levels, and improve insulin resistance, which is of great significance for maintaining glucose homeostasis

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(Balducci et al. 2014; Boulé et al. 2001; Magkos et al. 2020; Snowling and Hopkins 2006). Several studies have shown that a combination of aerobic and resistance training, i.e., combined exercise, is more effective in alleviating diabetes than aerobic or resistance training alone (Sampath et al. 2019). Therefore, many major international organizations/guidelines in this field, including the European Society of Cardiology, the American College of Sports Medicine, the Belgian Physiotherapy Association, and Exercise & Sports Science Australia, recommend combined exercise as a necessary non-pharmacological treatment for diabetes (Colberg et al. 2010; Gentzel 2013; Hordern et al. 2012; Rydén et al. 2013).

Considering only the type of exercise is not sufficient, because different combinations of exercise intensity and duration may affect the fat distribution, blood pressure, and blood glucose of patients in different ways. Some studies have shown that high-intensity interval training (HIIT) has the same or even better outcomes than moderate continuous training (MCT) (Gibala and Little 2010) and is a viable alternative for a variety of conditions such as diabetes (Mitranun et al. 2014), cardiovascular disease (Dun et al. 2019), and obesity (Marquis-Gravel et al. 2015).

Although the above-recommended combination of exercises and HIIT as an exercise regimen has an excellent fat-burning effect and can effectively control diabetes, it is more demanding on the physical fitness of patients with diabetes and does not apply to all DM patients; thus it is not conducive to long-term adherence of DM patients. In addition, it is recommended that patients maintain 60% of maximum oxygen consumption when performing aerobic exercise (i.e., the heart rate during exercise should be maintained at roughly 170 minus years of age [170 − age]). The duration and frequency of exercise should be 30–60 minutes per session, once a day or 4–5 times a week. However, this recommended exercise behavior, in addition to being inaccurate/not easily estimated/not easily maintained in terms of oxygen consumption, ignores the optimal duration and frequency of exercise corresponding to the resistance training often used by overweight diabetic patients, and the recommendation lacks experimental support and is not highly credible.

In order to solve the above two problems, we can, firstly, find the optimal combination of exercise that patients with diabetes more readily accept to guide them in their exercise routine. Secondly, specific exercise routines (such as walking, climbing stairs, brisk walking, and jogging) can be converted into low, moderate, or high exercise intensities to replace the calculation of oxygen consumption, thus eliminating the need for patients to measure how much oxygen they consume. Therefore, this study aimed to analyze the relationship between different exercise behaviors and various indicators of DM in 3867 diabetic patients through a cross-sectional study, and to find the optimal combination of exercise frequency, exercise duration, and exercise intensity by analyzing the effect of each exercise behavior on the indicators as well as the recommended exercise duration to relieve diabetes symptoms at different exercise frequencies and intensities. It fully respects the preference of diabetic patients in exercise choice, simplifies the process of measuring their exercise intensity, and is more readily accepted by diabetic patients; at the same time, it can provide scientific and practical personalized exercise guidance for diabetic patients, promote the transformation of disease treatment to health management, and thus improve the health literacy and survival quality of diabetic patients.

Methods

Study subjects and data sources

The data for this cross-sectional study were obtained from the physical examination data and questionnaire results from the Third Xiangya Hospital of Central South University from 2020 to 2021 (n = 103,649). Informed written consent was obtained from all participants, and the study protocol was approved by the Ethics Committee of the Third Xiangya Hospital of Central South University (no. 22206). The duplicates, blanks, abnormalities, and data that did not meet the nadir criteria (n = 57,324) were removed, leaving 46,325 participants, including 3867 diabetic patients and 42,458 healthy people. The inclusion criteria for diabetic patients were as follows: (1) age ≥ 18 years; (2) self-reported prior diagnoses by healthcare professionals; (3) fasting blood glucose ≥ 7 mmol/L; (4) concentration of hemoglobin A1c (HbA1c) 6.5% or higher; (5) no history of other metabolic, hormonal, orthopedic, or cardiovascular diseases, and no current use of prescription drugs. The inclusion criteria for healthy people were as follows: (1) age ≥ 18 years; (2) no history of diabetes, hypertension, or other chronic diseases; (3) fasting blood glucose < 7 mmol/L; (4) HbA1c concentration lower than 7.0%; (5) no history of other metabolic, hormonal, orthopedic, or cardiovascular diseases, and no current use of prescription drugs (Dalong 2021).

Questionnaire data

The participants' basic information, lifestyle habits, mental status, and exercise behavior were obtained (Table 1). Basic information included name, gender, ethnicity, marriage, education level, occupation, personal medical history, family history, and allergy history; lifestyle habits included smoking habits (daily/frequent/non-smoking/quit smoking), drinking habits (drinking/non-drinking/abstaining from drinking for more than 1 year), sleeping habits (good/fair/poor), and eating habits (good/fair/poor). Among them,

Table 1 Questionnaire data collation

		0 points	1 point	2 points	Score
Basic information	Name, gender, ethnicity, marriage, education level, occupation, personal medical history, family history, allergy history				
Lifestyle habits	Smoking habits	Daily/frequent/non-smoking/quit smoking (according to participants' self-reports)			
	Drinking habits	Drinking/non-drinking/abstaining from drinking for more than 1 year (according to participants' self-reports)			
	Sleeping habits	Good/fair/poor (according to participants' self-reports)			
	Eating habits	–	Not being able to eat on time > 3 times a week	–	Good: 0–1 Fair: 2–3 Poor: 4–6
		–	Midnight snacking > 1 time a week		
		–	Overeating		
		–	Salty dietary taste		
		–	Poor dietary habits (preferring to eat pickled, smoked, high fat, dessert, spicy, hot, fast food)		
		–	No staple food structure		
Mental status	Moody	No	Occasionally	Often	Good: 0–3 Fair: 4–9 Poor: 10–18
	Easily excited and angered				
	Nervous				
	Impatient				
	Lacking enthusiasm				
	Anxious				
	Depressed				
	Having difficulty concentrating				
Exercise behavior	Exercise frequency	1–2 times a week, 3–5 times a week, > 5 times a week			
	Exercise duration	< 30 minutes, 30–60 minutes, > 60 minutes			
	Exercise intensity	Low intensity	Maximum heart rate percentage < 64%, normal heartbeat and respiration	Exercise methods include walking	
		Moderate intensity	Maximum heart rate percentage 64–76%, heartbeat and respiration accelerated but not rapid	Exercise methods include brisk walking, jogging, swimming, cycling, Tai Chi, yoga, ballroom dancing, strength exercise	
		High intensity	Maximum heart rate percentage > 76%, rapid heartbeat and breathing, muscle pain	Exercise methods include aerobics, running, fast climbing, stair climbing, ball games	

good or bad eating habits were evaluated by the scores for six specific behaviors, including eating three meals on time, frequent midnight snacking, overeating, dietary taste, dietary habits, and staple food structure. One point was recorded for each of the following: not being able to eat on time more than three times a week, eating midnight snacks more than once a week, overeating, salty dietary taste, or poor dietary habits (preferring to eat pickled, smoked, high fat, dessert, spicy, hot, fast food). A total score of 0–1 was defined as "good," 2–3 was defined as "fair," and 4–6 was defined as "poor." Mental status was rated by the frequency of eight emotional displays: "moody," "easily excited and angered," "nervous," "impatient," "lacking enthusiasm," "anxious," "depressed," and "having difficulty concentrating." There were three answers: "often" with 2 points, "occasionally" with 1 point, and "never" with 0 points. A total score of 0–2 was defined as "good," 4–9 as "fair," and 10–18 as "poor."

Exercise behavior includes exercise frequency (1–2 times per week, 3–5 times per week, > 5 times per week), exercise duration (< 30 minutes, 30–60 minutes, > 60 minutes), and exercise intensity (low intensity, moderate intensity, high intensity). Exercise intensity is judged based on the maximum heart rate percentage of exercise (Guoping et al. 2023). Low intensity is defined as a maximum heart rate percentage < 64%, regular heartbeat, and respiration; exercise methods include walking. Medium intensity is defined as a maximum heart rate percentage of 64–76%, and heartbeat and respiration are accelerated but not rapid; exercise methods include brisk walking, jogging, swimming, cycling, Tai Chi, yoga, ballroom dancing, and strength exercise. High intensity is defined as a maximum heart rate percentage > 76%, rapid heartbeat and breathing, and muscle pain; exercise methods include aerobics, running, fast climbing, stair climbing, and ball games.

Physical measurements and assessment

Body mass index (BMI) was calculated from height and weight (kg/m^2). Physical measurements included height, weight, waist circumference, hip circumference, right upper arm systolic blood pressure, and right upper arm diastolic blood pressure, measured using the same method and instruments. The standard assessment criteria for these indicators were as follows: BMI (18.5–23.9 kg/m^2); waist circumference (men < 85 cm; women < 80 cm); hip circumference (men 85–105 cm; women 75–80 cm) (Youfa 2022); right upper arm systolic blood pressure (90–140 mmHg); right upper arm diastolic blood pressure (60–90 mmHg) (Jing 2021).

Blood measurement and evaluation

Fasting blood samples were collected after overnight fasting to provide total cholesterol (Tch), triglyceride, HDL cholesterol (HDL-C), LDL cholesterol (LDL-C), and fasting plasma glucose (FPG) levels. These indicators were evaluated as follows: Tch (normal: < 5.2 mmol/L; borderline high: 5.2–6.1 mmol/L; high: ≥ 6.1 mmol/L), triglycerides (low: < 0.56 mmol/L; normal: 0.56–1.70 mmol/L; high: ≥ 1.70 mmol/L), HDL-C (low: ≤ 1.04 mmol/L; normal: 1.04–1.55 mmol/L; high: ≥ 1.55 mmol/L), LDL-C (optimal: 1.8–2.6 mmol/L; near optimal: 2.6–3.4 mmol/L; borderline high: 3.4–4.1 mmol/L; high: ≥ 4.1 mmol/L), FPG (normal: 3.89–6.10 mmol/L; borderline high: 6.10–7.00 mmol/L; high: ≥ 7.00 mmol/L) (Junren et al. 2016).

Statistical analysis

All statistical analyses were performed using SPSS (28.0.0.0) and R (3.6.3) software. The chi-square test was used to detect whether there were differences in demographic characteristics, living habits, and health status between healthy people and diabetic patients. Demographic characteristics included gender (male/female), race (Han/ethnic minorities), marital status (married including cohabitation/unmarried); living habits included smoking habits (daily/often/never/quit smoking), drinking habits (drinking/never drinking/quit drinking for more than 1 year), eating habits (good/fair/poor), and sleeping habits (good/fair/poor). Health status included mental status (good/fair/poor), BMI classification (underweight/normal/overweight/obese), and Tch (normal, borderline high, high), triglyceride (low, normal, high), HDL-C (low, normal, high), LDL-C (optimal, near optimal, borderline high, high), and FPG levels (normal, borderline high, high). The non-parametric Mann–Whitney test was used to analyze various continuous indicators (height, weight, BMI, waist circumference, right upper arm systolic blood pressure, right upper arm diastolic blood pressure, hip circumference, Tch, triglyceride, HDL-C, LDL-C, HDL-C/Tch ratio, and FPG) in healthy people and diabetic patients. The non-parametric Kruskal–Wallis test was used to determine whether there were statistical differences in various continuous indicators under different exercise frequency, duration, and intensity combinations in diabetic patients. Polar area diagrams were used to show the levels of each index under different exercise behaviors. The polar area graph was used to show the best exercise duration at a given frequency and intensity. According to age stratification (young and middle-aged < 60 years old/elderly > 60 years old), the differences in different exercise behaviors were compared between groups.

Mendelian randomization analysis

We applied the Mendelian randomization (MR) method, using two datasets (ebi-a-GCST007517 and ukb-b-8764) from OpenGWAS (https://gwas.mrcieu.ac.uk/) for a two-sample MR analysis to test whether there is a direct causal relationship between exercise and type 2 diabetes. The ebi-a-GCST007517 dataset included 298,957 patients with type 2 diabetes, and the ukb-b-8764 dataset included 460,376 participants from the UK Biobank who had been physically active for the last 4 weeks. Causal estimation by MR analysis is not valid without fulfilling three critical assumptions: (1) the variables are correlated with the risk factor of interest (correlation assumption), (2) they share no common cause with the outcome (independence assumption), and (3) they do not affect the results except through the risk factor (exclusion restriction assumption) (Davies et al. 2018).

The importance level of the entire genome is defined as $p < 5*10^{-8}$, which satisfies the correlation hypothesis and correlates the instrumental variables with the results. We calculated F-statistics using the previous equation and estimated the intensity per single-nucleotide polymorphism (SNP) (Papadimitriou et al. 2020). In the random-effects meta-analysis, an inverse-variance weighting (IVW) method combines SNP exposure and SNP results from coefficients to estimate causal effects (Deng et al. 2022). Several sensitivity analyses were performed to determine the presence of pluripotency in causal estimation. Cochran's Q was calculated to examine the heterogeneity of individual causal effects. A p-value < 0.05 was considered to indicate the presence of pluripotency.

We used a complementary weighting method, assuming that at least 50% of instrumental variables were valid, ranking the MR estimates for each instrumental variable to give valid MR estimates (Bowden et al. 2016). The TwoSampleMR (version 0.5.6) package was used for statistical analyses in R software (version 4.1.0).

Ethics statement

The present study protocol was reviewed and approved by the Ethics Committee of the Third Xiangya Hospital of Central South University (approval no. 22206). Informed consent was submitted by all participants when they were enrolled.

Results

Participant characteristics

A total of 46,325 participants were included in our study, including 3867 with diabetes and 42,458 healthy persons. The two groups were statistically different in three aspects: demographic characteristics, living habits, and health status (Table 2). Regarding demographic characteristics, we found that the number of men with diabetes was significantly greater than the number of women ($p < 0.01$), accounting for 77.11% of the diabetic population in this study. At the same time, we found that 97.39% of diabetic patients were married. In terms of living habits, we found that diabetic patients tended to prefer smoking ($p < 0.01$) and drinking ($p < 0.01$), but their eating habits were better than those of healthy people, which may be related to diabetic patients paying more attention to diet management. Diabetic patients were more likely to have poor sleep quality than healthy people ($p < 0.01$). Regarding health status, we found that patients with diabetes had better mental status than healthy people. However, according to the BMI classification, we found that patients with diabetes were more likely to be overweight and obese (DM: 71.6%, healthy: 41.4%, $p < 0.01$), and more likely to have elevated Tch (DM: 47.94%, healthy: 35.21%, $p < 0.01$), triglyceride (DM: 61.91%, healthy: 30.18%, $p < 0.01$) and LDL-C (DM: 25.83%, healthy: 22.15%, $p < 0.01$). And more diabetic patients had low HDL-C (DM: 28.06%, healthy: 13.77%, $p < 0.01$). The percentage of diabetic patients with normal FPG was only 4.37%, much lower than that of healthy people (Table 2).

Non-parametric Mann–Whitney tests showed that the average BMI and triglyceride and FPG levels of diabetic patients in this study exceeded the normal standard (18.5–23.9, 0.56–1.70 mmol/L, 3.89–6.10 mmol/L). The mean values of other indicators were maintained at appropriate levels in the diabetic population. However, most of the indicators were higher in diabetic patients than in the healthy population (including height, weight, waist circumference, hip circumference, systolic blood pressure, diastolic blood pressure, and Tch). The results showed highly significant statistical differences ($p < 0.01$) (Supplementary table 1). The results of the non-parametric Kruskal–Wallis test (Supplementary Table 2) showed that except for LDL-C ($p = 0.681 > 0.05$), the indicators were significantly different among the groups with different exercise habits ($p < 0.01$).

The best combination of exercises for diabetes

The physical appearance and blood pressure, blood lipid, and blood glucose measurements for different exercise combinations are shown as averages in Fig. 2. We found that the combination of exercise > 3 times a week showed significant differences compared with no exercise, regardless of the duration and intensity of each exercise session ($p < 0.05$) (Table 3). BMI, waist circumference, and hip circumference showed that the best combination was > 5 times a week, > 60 minutes of intense exercise (Fig. 1a). Nevertheless, the exercise groups of > 60 minutes, 30–60 minutes, and < 30 minutes did not exhibit significant differences between groups ($p > 0.05$), and the group differences between the high-intensity, moderate, and low-intensity groups were not significant ($p > 0.05$) (Table 3). Therefore, exercising > 5 times a week was associated with smaller waist and hip circumference and lower BMI. Systolic and diastolic blood pressure values remained at normal levels (90–139 mmHg and 60–89 mmHg) in all groups, so they could not be used to evaluate the effect of exercise (Fig. 1b).

From the perspective of Tch and triglyceride, the best combination for blood lipid control was high intensity, > 5 times a week, > 60 minutes each time. In terms of HDL-C, the best combination was moderate intensity, > 60 minutes five times a week (Fig. 1c). There was no significant difference between the high-intensity group and the moderate- and low-intensity groups ($p > 0.05$) (Table 3). As shown in Supplementary Table 2, there was no significant difference in LDL-C levels among all groups ($p = 0.681$). Therefore, exercising > 5 times a week for > 30 minutes each time can effectively control blood lipid levels, regardless of the intensity.

The optimal combination of glycemic control, measured by FPG, was high intensity for 30–60 minutes and > 5 times per week (Fig. 1d). However, there was no significant difference between the group who exercised > 5 times per week and the group who exercised 3–5 times per week ($p > 0.05$), or between the group who exercised 30–60 minutes per time and the group who exercised > 60 minutes per time ($p > 0.05$). However, there was a highly significant difference between the group that exercised for 30–60 minutes and the group that exercised for < 30 minutes per session ($p = 0.003$), and there was no significant difference between the high-intensity group and either the moderate-intensity or the low-intensity group (Table 3).

Table 2 Characteristics of participants

Characteristic	Type	Groups (%)		Total	*p*
		DM	Healthy		
Gender	Female	885 (22.89)	20,973 (49.40)	21,858 (47.18)	0.000
	Male	2982 (77.11)	21,485 (50.60)	24,467 (52.82)	
Total		3867	42,458	46,325	
Race	Han nationality	3761 (97.26)	40,855 (96.22)	44,616 (96.31)	0.001
	National minority	106 (2.74)	1603 (3.78)	1709 (3.69)	
Total		3867	42,458	46,325	
Marital status	Married (including cohabitation)	3766 (97.39)	35,521 (83.66)	39,287 (84.81)	0.000
	Unmarried	101 (2.61)	6937 (16.34)	7038 (15.19)	
Total		3867	42,458	46,325	
Smoking habits	No smoking	2270 (58.70)	30,931 (72.85)	33,201 (71.67)	0.000
	Frequent passive smoking	140 (3.62)	1812 (4.27)	1952 (4.21)	
	Smoking every day	1261 (32.61)	8698 (20.49)	9959 (21.50)	
	Have quit smoking	196 (5.07)	1017 (2.40)	1213 (2.62)	
Total		3867	42458	46,325	
Drinking habits	No drinking	2249 (58.16)	30612 (72.10)	32,861 (70.94)	0.000
	Drinking	1516 (39.20)	11484 (27.05)	13,000 (28.06)	
	Abstinence from alcohol (> 1 year)	102 (2.64)	362 (0.85)	464 (1.00)	
Total		3867	42458	46,325	
Dietary habits	Poor	699 (18.08)	13545 (31.90)	14,244 (30.75)	0.000
	Fair	1818 (47.01)	18,303 (43.11)	20,121 (43.43)	
	Good	1350 (34.91)	10,610 (24.99)	11,960 (25.82)	
Total		3867	42,458	46,325	
Sleep quality	Poor	330 (8.53)	3197 (7.53)	3527 (7.61)	0.000
	Fair	1835 (47.45)	21,541 (50.73)	23,376 (50.46)	
	Good	1702 (44.01)	17,720 (41.74)	19,422 (41.93)	
Total		3867	42,458	46,325	
Psychological states	Poor	153 (3.96)	3075 (7.24)	3228 (6.97)	0.000
	Fair	898 (23.22)	13,328 (31.39)	14,226 (30.71)	
	Good	2816 (72.82)	26,055 (61.37)	28,871 (62.32)	
Total		3867	42,458	46,325	
BMI classification	≤18.4 (underweight)	21 (0.54)	1785 (4.20)	1806 (3.90)	0.000
	18.5–23.9 (normal weight)	1077 (27.85)	23,100 (54.41)	24,177 (52.19)	
	24–27.9 (overweight)	1825 (47.19)	13,881 (32.69)	15,706 (33.90)	
	≥28 (obesity)	944 (24.41)	3692 (8.70)	4636 (10.01)	
Total		3867	42,458	46,325	
Tch classification	<5.2 mmol/L (normal)	2013 (52.06)	27,510 (64.79)	29,523 (63.73)	0.000
	5.2–6.1 mmol/L (borderline high)	1072 (27.72)	10,661 (25.11)	11,733 (25.33)	
	≥6.1 mmol/L (high)	782 (20.22)	4287 (10.10)	5069 (10.94)	
Total		3867	42,458	46,325	
Triglyceride classification	<0.56 mmol/L (low)	36 (0.93)	2685 (6.32)	2721 (5.87)	0.000
	0.56–1.70 mmol/L (normal)	1437 (37.16)	26,958 (63.49)	28,395 (61.30)	
	≥1.70 mmol/L (high)	2394 (61.91)	12,815 (30.18)	15,209 (32.83)	
Total		3867	42,458	46,325	
HDL cholesterol classification	≤1.04 mmol/L (low)	1085 (28.06)	5845 (13.77)	6930 (14.96)	0.000
	1.04–1.55 mmol/L (normal)	2428 (62.79)	27,785 (65.44)	30,213 (65.22)	
	≥1.55 mmol/L (high)	354 (9.15)	8828 (20.79)	9182 (19.82)	
Total		3867	42,458	46,325	

Table 2 (continued)

Characteristic	Type	Groups (%)		Total	p
		DM	Healthy		
LDL cholesterol classification	<1.8 mmol/L (optimal)	685 (17.71)	2712 (6.39)	3397 (7.33)	0.000
	1.8–2.6 mmol/L (optimal)	955 (24.70)	13,281 (31.28)	14,236 (30.73)	
	2.6–3.4 mmol/L (near optimal)	1228 (31.76)	16,719 (39.38)	17,947 (38.74)	
	3.4–4.1 mmol/L (borderline high)	666 (17.22)	7137 (16.81)	7803 (16.84)	
	≥4.1 mmol/L (high)	333 (8.61)	2609 (6.14)	2942 (6.35)	
Total		3867	42,458	46,325	
FPG classification	3.89–6.10 mmol/L (normal)	169 (4.37)	42,458 (100.00)	42,627 (92.02)	0.000
	6.10–7.00 mmol/L (borderline high)	244 (6.31)	0 (0.00)	244 (0.53)	
	≥7.00 mmol/L (high)	3454 (89.32)	0 (0.00)	3454 (7.46)	
Total		3867	42,458	46,325	

Table 3 Intergroup comparison of exercise behavior in diabetic patients

	BMI	WL	HL	SP	DP	Tch	TAG	HDL-C	LDL-C	FPG
Exercise frequency										
>5 times - 3–5 times	.018	.374	.014	.004	.077	.016	.000	.005	–	1.000
>5 times - 1–2 times	.000	.000	.000	.000	.054	.001	.000	.000	–	.000
>5 times - No exercise	.000	.000	.000	.006	.002	.000	.000	.000	–	.000
3–5 times - 1–2 times	.000	.008	.000	.413	1.000	1.000	.000	.000	–	.004
3–5 times - No exercise	.000	.000	.000	1.000	1.000	.001	.000	.000	–	.000
1–2 times - No exercise	.735	.364	1.000	.297	1.000	.212	.346	1.000	–	.453
Total	.000	.000	.000	.000	.003	.000	.000	.000	.072	.000
Exercise duration										
>60 min - 30–60 min	1.000	1.000	1.000	–	–	1.000	.149	1.000	–	1.000
>60 min - <30 min	.796	.692	.357	–	–	.945	.000	.001	–	.113
>60 min - No exercise	.000	.000	.000	–	–	.000	.000	.000	–	.000
30–60 min - <30 min	.494	.307	1.000	–	–	1.000	.000	.003	–	.003
30–60 min - No exercise	.000	.000	.000	–	–	.000	.000	.000	–	.000
<30 min - No exercise	.001	.014	.040	–	–	.047	.007	1.000	–	.467
Total	.000	.000	.000	.525	.164	.000	.000	.000	.060	.000
Exercise intensity										
High - Moderate	1.000	1.000	1.000	–	1.000	1.000	1.000	1.000	–	1.000
High - Low	1.000	.183	1.000	–	.002	1.000	.384	.424	–	1.000
High - No exercise	.000	.000	.000	–	1.000	.004	.000	.016	–	.000
Moderate - Low	1.000	1.000	1.000	–	.100	1.000	1.000	1.000	–	1.000
Moderate - No exercise	.000	.000	.001	–	1.000	.002	.000	.000	–	.000
Low - No exercise	.000	.000	.000	–	.001	.000	.000	.000	–	.000
Total	.000	.000	.000	.057	.000	.000	.000	.000	.545	.000

WL, waistline; *HL*, hipline; *SP*, systolic pressure; *DP*, diastolic pressure; *Tch*, total cholesterol; *TAG*, triglyceride; *HDL-C*, high-density lipoprotein cholesterol; *LDL-C*, low-density lipoprotein cholesterol; *FPG*, fasting plasma glucose

Therefore, exercising > 3 times a week for > 30 minutes each time can effectively control blood glucose, regardless of the intensity.

In conclusion, for people with diabetes, exercise > 5 times a week and > 30 minutes each time, regardless of the intensity, can lead to a decrease in waist and hip circumference, BMI, and blood lipid and glucose levels.

The polar graph (Fig. 2) showed that low-intensity exercise 1–2 times a week required 30–60 minutes or more per exercise session to achieve the desired effect. However, in moderate

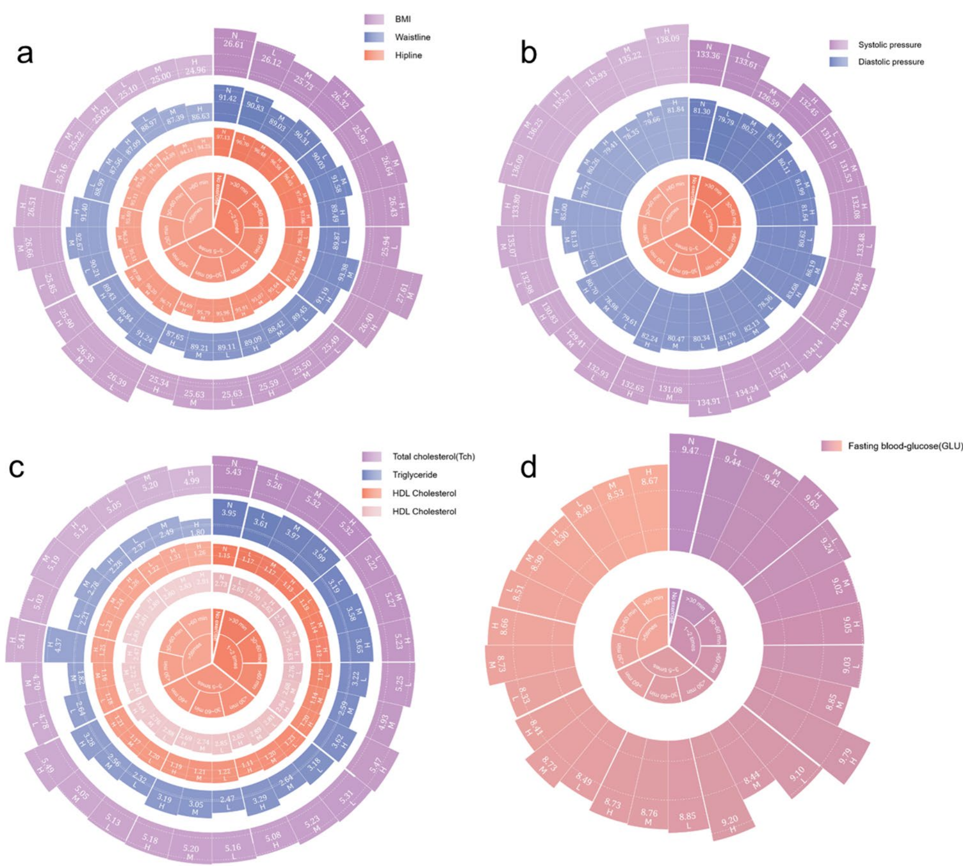

Fig. 1 Polar area diagrams. Diabetic patients with moderate to high-intensity exercise > 5 times a week and > 60 minutes each time have a healthier appearance and blood lipid and blood glucose levels. Blood pressure maintained in the appropriate range. (**a**) Average BMI, waist circumference, and hip circumference corresponding to different exercise behaviors; (**b**) average systolic and diastolic blood pressure values corresponding to different exercise behaviors; (**c**) average total cholesterol, triglyceride, high-density lipoprotein cholesterol, and low-density lipoprotein cholesterol levels corresponding to different exercise behaviors; (**d**) average fasting blood glucose values corresponding to different exercise behaviors

and high exercise intensity conditions, it did not require a long exercise time, which may be related to the compensation of increased exercise intensity. However, more intensive exercise (≥ 5 times per week) was associated with more beneficial effects (lower BMI, Tch, triglyceride, FPG; smaller waist circumference, hip circumference; higher HDL-C level).

The results for group differences in different exercise behaviors between young and middle-aged diabetic patients and elderly diabetic patients stratified by age are shown in Supplementary Tables 3 and 4. It is worth noting that our data showed that there were no significant differences in any indicator among different exercise intensity groups in elderly diabetic patients aged over 60 years (Supplementary Table 4).

A direct causal relationship between exercise and diabetes

Inverse variance weighting ($p = 0.027$, OR = 0.18, 95% CI) and weighted median ($p = 0.023$, OR = 0.15, 95% CI) showed that exercise reduced the prevalence of diabetes by a two-sample Mendelian randomization analysis (Fig. 3). The heterogeneity ($Q = 2.37, p = 0.30$) and level pleiotropy ($p = 0.37$) were tested. Our results confirm a direct causal relationship between exercise and diabetes and that exercise is a protective factor for diabetes.

Discussion

Our results suggest that exercise > 5 times a week and > 30 minutes each time has a good effect on reducing waist and hip circumference, lowering BMI and blood lipids, and controlling blood glucose, which is similar to the findings of Faulkner et al., who recommended 30 minutes per day (≥5 times a week; moderate intensity) of aerobic and strength exercise to improve blood glucose (such as lowering glucose levels without causing hypoglycemia) and cardiovascular parameters (such as lowering exaggerated resting heart rate and systolic blood pressure) (Balducci et al. 2014; Farinha et al. 2018; Faulkner et al. 2014).

However, Hamasaki et al. found that only about 30% of diabetic patients reached the recommended level of physical activity, and a common reason for not exercising was lack of time (Hamasaki 2018). Considering that a large proportion of diabetic patients cannot exercise more than five times per week, we also analyzed the problem of how to schedule exercise under conditions of limited exercise frequency and exercise intensity. We found that if a person is only fit for low-intensity exercise, and the amount of time they exercise is minimal (only one or two times per week), then they should consider extending the duration of exercise each time. In this case, 30–60 minutes and > 60 minutes of exercise are good choices. However, if there

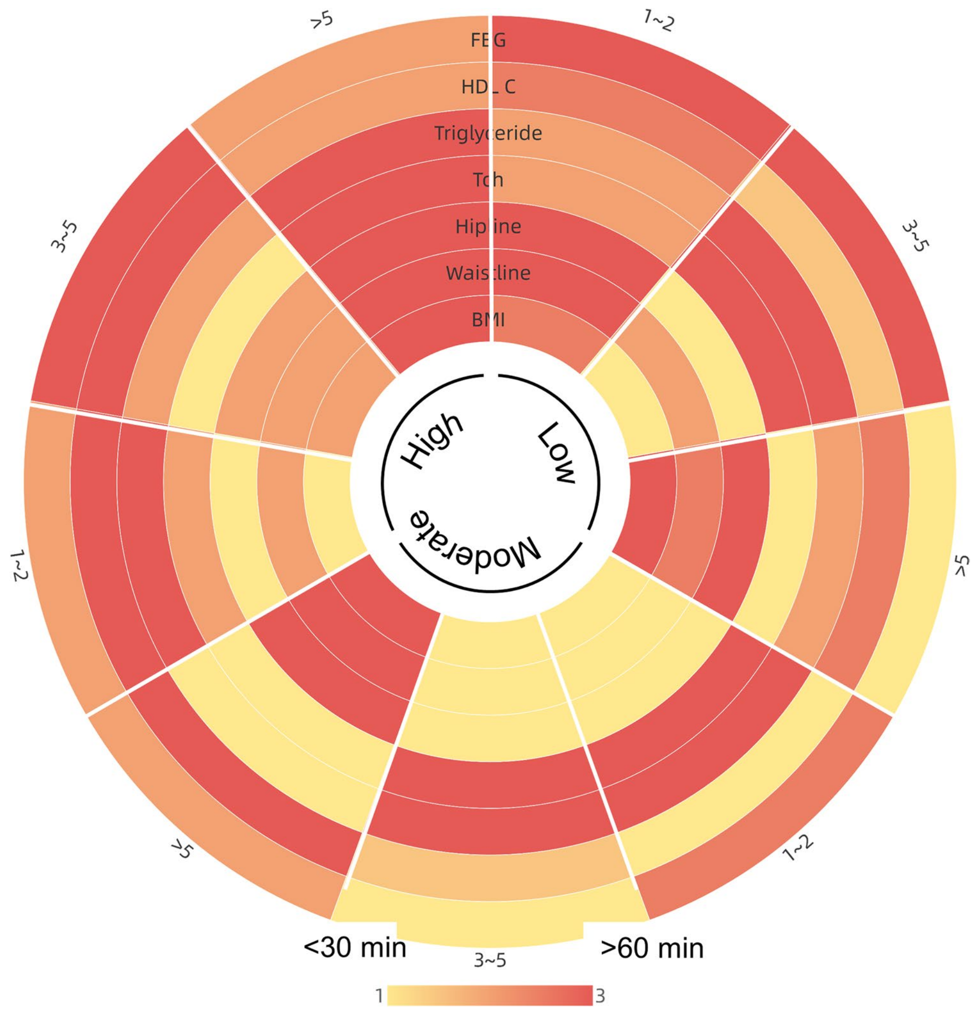

Fig. 2 The polar thermal diagram was drawn based on the polar area graph and the non-parametric Kruskal–Wallis test results to show the exercise duration required by different exercise intensities and frequencies to achieve the desired effect. The shades of color indicate the duration of each session, with red indicating more than 60 minutes

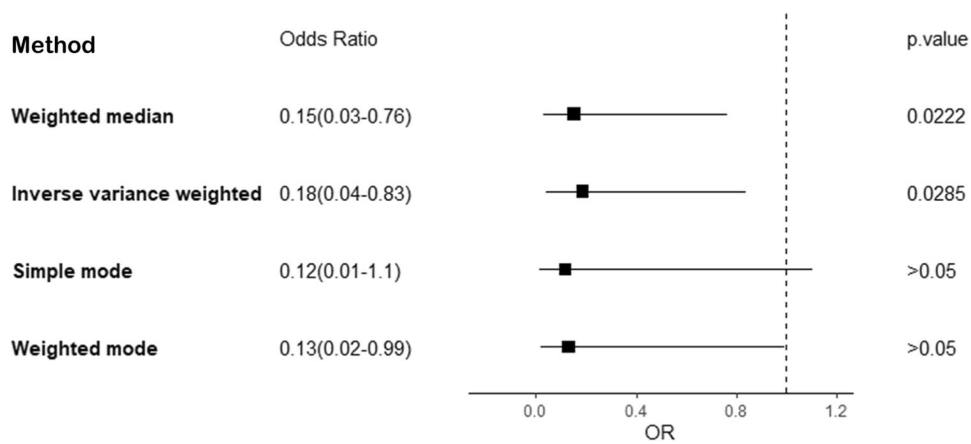

Fig. 3 MR estimates between exercise and type 2 diabetes mellitus (T2DM) risk OR: odds ratio; CI: confidence intervals

are more opportunities to exercise every week, each exercise session can be shortened. Low frequency is closely related to long duration, and high frequency is closely related to short duration. In order to achieve better hypoglycemic effects in low-intensity exercise, it is suggested that diabetic patients choose the appropriate time for daily exercise according to their conditions. Blindly extending a workout may result in disproportionate effort and results.

In addition, we found that with the increase in exercise intensity, the association between low frequency and long duration weakened, which may be due to the exercise intensity itself, suggesting that diabetic patients with limited exercise times per week can save much time by increasing exercise intensity if their physical conditions permit. Interestingly, we found that under the condition of high intensity and high frequency of exercise (> 5 times per week), a longer duration of exercise was still required to achieve the best effect, which may be related to the physical fitness of patients who chose this exercise behavior. Exercise intensity, frequency, and duration are more likely preferred by people with diabetes who are physically fit. Our data show that this type of exercise is associated with healthier body composition, lipid content, and glucose levels. There was no significant difference in each index among different exercise intensity groups in elderly diabetic patients, suggesting that it is not necessary to pursue a high-intensity exercise regimen when choosing an exercise mode in elderly diabetic patients.

Among 46,325 subjects, 69.77% of diabetic patients adhered to an exercise routine, which was higher than that of healthy people (58.70%), indicating that diabetic patients had a more vital awareness of cultivating exercise habits, which may be related to the fact that diabetic patients received more physical exercise advice. Our survey results showed that only 1.89% of diabetic patients had the habit of strength exercise in daily life, and only 4.76% of healthy people had the habit of strength exercise. More people chose easy exercise methods such as walking and jogging that did not need professional equipment. This means that although many studies have shown that the combination of aerobic training and resistance training may be the most effective way to alleviate diabetes (Balducci et al. 2004; Cuff et al. 2003; Reddy et al. 2019; Schwingshackl et al. 2014), the proportion of the number of people shows that resistance training has not been adopted and applied by many people, suggesting that we need to carry out more combined training education for diabetic patients.

In our study, we collected the forms of exercise selected by patients with diabetes and classified the exercise intensity according to the percentage of maximum heart rate. It also found the best combination of exercise frequency, intensity, and duration for diabetic patients, providing scientific and practical personalized exercise guidance for diabetic patients. Our results suggest that exercising > 5 times a week and > 30 minutes each time has a good effect on reducing waist and hip circumference, lowering BMI and blood lipids, and controlling blood glucose. Furthermore, it is unnecessary to pursue a high-intensity exercise mode when choosing exercise mode in elderly diabetic patients.

Our study also had some limitations. We did not consider the effects of blood pressure, lipid-lowering, and hypoglycemic drugs. We looked at people with type 1 and type 2 diabetes, but we did not perform a separate analysis of those two types of diabetes. The characteristics of cross-sectional studies prevent us from determining a causal relationship between the DM index and exercise pattern selection. Therefore, we performed a two-sample MR on two OpenGWAS datasets. The results showed a direct causal relationship between exercise and diabetes risk. However, the etiological link between exercise behavior and diabetes is not clear here, and further experiments will be needed to verify this in the future. The sample size in our study was small. However, based on a small sample, we have performed our analysis as rigorously as possible. The results of the MR analysis can also be used to verify our analysis. Further experiments may be needed to confirm our results.

Exercise can help individuals slim down and shape up, reduce fat, and lower sugar, but a high level of exercise does not directly affect lowering blood pressure. Exercising > 5 times a week and > 30 minutes was the most practical combination of exercise for diabetes relief. Low exercise frequency must be paired with longer exercise duration at low exercise intensities to achieve the desired effect. The association between low exercise frequency and long exercise duration decreases as exercise intensity increases. The levels of all indicators in elderly diabetic patients were unrelated to exercise intensity.

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Authors' contributions Conception or design: Yanhui Lin; Yuxin Sun; Ziran Zhang

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Drafting the work or revising: Yanhui Lin, Yuxin Sun; Tong Wu; Zhengran Li; Fanke Meng; Min Fu

Final approval of the manuscript: Yanhui Lin; Fanke Meng; Min Fu

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Data availability (data transparency) Data and material are available from the authors.

Code availability Code is available from the authors.

Declarations

Ethics approval The study protocol was approved by the Ethics Committee of the Third Xiangya Hospital of Central South University (No. 22206)

Consent to participate Informed written consent was obtained from all participants.

Consent for publication All the authors consent for data or images of the article to be published.

Conflicts of interest No potential conflict of interest relevant to this article was reported.

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