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REVIEW

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Revisiting traditional Chinese exercise in prediabetes: effects on glycaemic and lipid metabolism – a systematic review and meta-analysis

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Abstract

Background and objectives Most existing studies have primarily focused on the effects of Traditional Chinese Exercises (TCEs) on glycemic control in individuals with prediabetes, while specific recommendations for managing dyslipidemia in this population remain insufficient. Moreover, there is a lack of systematic research and conclusive evidence regarding the optimal exercise dose required to achieve metabolic improvements in individuals with prediabetes. Therefore, this meta-analysis aims to comprehensively evaluate the efficacy of TCEs in improving glycemic and lipid profiles in individuals with prediabetes and to explore the potential impact of exercise dose on these metabolic parameters.

Methods A comprehensive search of six databases (PubMed, Web of Science, Cochrane Library, Embase, CNKI, and WanFang Data) followed PRISMA guidelines to identify randomized controlled trials (RCTs) on TCEs (e.g., "Tai Chi," "Yijinjing,""Baduanjin") and prediabetes (e.g., "impaired glucose tolerance,""impaired glucose regulation") published up to November 10, 2024. Three reviewers independently screened studies, extracted data, and assessed bias risk. Meta-analysis and subgroup/meta-regression analyses were conducted using Stata 17 software. The review protocol is registered in PROSPERO (CRD42024615150).

Results A total of 15 studies involving 1,839 participants were included. The meta-analysis revealed that TCEs significantly improved HbA1c (MD = -0.28%; 95% CI: -0.38% to -0.18%; $P=0.001$), FBG (MD = -0.44 mmol/L; 95% CI: -0.53 to -0.34 mmol/L; $P<0.001$), 2hPG (MD = -1.16 mmol/L; 95% CI: -1.48 to -0.85 mmol/L; $P<0.001$), TC (MD = -0.31 mmol/L; 95% CI: -0.50 to -0.11 mmol/L; $P=0.002$), TG (MD = -0.28 mmol/L; 95% CI: -0.50 to -0.06 mmol/L; $P=0.012$), and HDL (MD = -0.28 mmol/L; 95% CI: -0.50 to -0.06 mmol/L; $P=0.012$) compared to control groups.

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Conclusions TCEs significantly improve prediabetics' blood glucose and lipid levels. The recommended exercise regimen is 30–50 min per session, 2–3 times per week, for at least three months.

Introduction

Prediabetes refers to a state where blood glucose levels are higher than usual but have not yet reached the diagnostic threshold for diabetes. It is a high-risk stage for developing diabetes and is also considered the only reversible "golden period" [1, 2]. According to the International Diabetes Federation (IDF) 2019 report, approximately 374 million people worldwide have prediabetes, accounting for 7.5% of the adult population [3]. This number is projected to rise to 548 million, or 8.6%, by 2045[3]. Without timely management, about 5–10% of individuals with prediabetes will progress to type 2 diabetes (T2D) each year, and approximately 70% will eventually develop T2D [3, 4]. The high prevalence and conversion rates of prediabetes present a significant burden on public health and healthcare expenditure [5]. Therefore, timely intervention and effective management strategies for prediabetes are crucial for preventing the onset of diabetes and its complications.

Lifestyle changes, particularly increasing physical activity levels, are more effective than medication alone in reversing prediabetes and preventing its progression to diabetes [6]. However, such interventions face many obstacles in real-world settings. Many patients struggle to adhere to regular moderate-intensity aerobic exercises (such as jogging or brisk walking) due to sedentary habits, physical limitations, and other factors [7–9]. For patients unable to follow lifestyle recommendations, pharmacological and dietary therapy provide an alternative option. However, while plant-based dietary therapies, such as okra consumption, may improve fasting blood glucose (FBG), their effects on longer-term indicators, such as glycated hemoglobin (HbA1c) [14], remain limited. Similarly, the long-term use of pharmacological treatments is constrained by such problems as adverse side effects [10], diminished efficacy upon discontinuation [11], weight regain [12], and recurrence of prediabetes [13], rendering these treatments less appropriate as sustainable strategies for long-term management of prediabetes. These limitations underscore the urgent need for more effective and sustainable approaches to address the multifaceted challenges of prediabetes management.

Under the "Exercise is Medicine" (EIM) concept, TCEs such as Tai Chi, Baduanjin, and Yijinjing have been widely adopted globally as effective disease prevention and management tools [15]. These practices, rooted in traditional Chinese medicine, are characterized by their low intensity, non-competitive nature, and high adherence. They emphasize the combination of breathwork, meditation, and physical movement, making them particularly suitable for middle-aged and elderly individuals with prediabetes, especially those with a weakened constitution [16]. In addition, TCEs are easy to learn, represent low-risk interventions with favorable outcomes, and do not require professional guidance or expensive resources, thus reducing implementation difficulty [17, 18]. This makes TCEs a more feasible and cost-effective intervention, especially in resource-limited communities or healthcare systems.

In recent years, TCEs have demonstrated significant potential in preventing and managing prediabetes, becoming an effective lifestyle intervention strategy. A previous meta-analysis [19] has only proven that TCEs positively affect blood glucose control in individuals with prediabetes. However, systematic assessments regarding the impact of exercise dosage on blood glucose and lipid profiles still need to be done. Moreover, prediabetes is often associated with metabolic disturbances, such as dyslipidemia, in addition to abnormal glucose metabolism. This may increase the risk of progression to T2D and cardiovascular diseases [20]. Although current guidelines emphasize enhanced lipid management for diabetes patients, there are few specific recommendations for addressing dyslipidemia in individuals with prediabetes [21]. Therefore, this meta-analysis aims to (1) comprehensively assess the effectiveness of TCEs in controlling blood glucose and lipid levels in individuals with prediabetes, (2) explore the optimal exercise prescription to improve glucose and lipid metabolism in prediabetes patients.

Protocol and registration

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [22] conducted this systematic review and meta-analysis. The protocol for this systematic review and meta-analysis has been registered in PROSPERO (CRD42024615150).

Search strategy and study selection

We conducted a comprehensive literature search in six databases: PubMed, Web of Science, Cochrane Library, Embase, CNKI, and WangFang Data, to identify randomized controlled trials (RCTs) on the effects of TCEs on individuals with prediabetes. The search was conducted from establishing each database until November 10, 2024. Three independent reviewers (RX, LD, and BW) performed the search and screened the eligible studies, with any disagreements resolved through consultation with a fourth reviewer (GS). Additionally, the reference lists of the included studies and relevant systematic reviews were checked for further potential eligible trials. A complete list of the search strategies can be found in Appendix 1.

Eligibility criteria

The studies were evaluated using the PICOS framework (Population, Intervention, Comparison, Outcome, and Study Design) [23]. Studies were included in the review if they met al.l of the following criteria:

Population

This study included research recruiting participants aged ≥ 18 years with prediabetes, excluding those with diagnosed diabetes, severe comorbidities, children, adolescents, and pregnant women. The diagnosis of prediabetes was based on the American Diabetes Association (ADA) criteria [24], which include any of the following conditions: fasting blood glucose levels between 5.6 and 6.9 mmol/L; HbA1c levels between 39 and 47 mmol/mol (5.7-6.4%); or a 2-hour plasma glucose level between 7.8 and 11.0 mmol/L in an oral glucose tolerance test (OGTT) (Table 1).

Intervention

The interventions included TCEs such as Tai Chi, Yijinjing, Baduanjin, and Shaolin Neigong, with detailed definitions of TCEs provided in Appendix 2.

Comparator

The control groups included health education, routine care, and waiting lists.

Outcome

The included studies were required to report at least one of the following outcomes:

Blood glucose control: HbA1c, FBG, postprandial 2-hour blood glucose (2hPG);

Blood lipid control: Total cholesterol (TC), triglycerides (TG), high-density lipoprotein (HDL), low-density lipoprotein (LDL).

Study design

The study design was restricted to RCTs.

Table 1 Diagnostic criteria for prediabetes

Parameter	Test used	Prediabetes range	
		mg/dl or % (HbA1c)	mmol/l or mmol/mol(HbA1c)
IFG	FPG test	100–125	5.6–6.9
IGT	OGTT	140–199	7.8–11.0
HbA1c	HbA1c test	5.7–6.4	39–46

FPG, fasting plasma glucose; HbA1c, haemoglobin A1c; IFG, impaired fasting glucose; IGT, impaired glucose tolerance; OGTT, oral glucose tolerance test

Exclusion criteria

Studies were excluded if they met any of the following criteria:

1. Non-randomized controlled trials.
2. Interventions involving pharmacological treatments or dietary control.
3. Studies that were not peer-reviewed, including theses, research protocols, conference abstracts, and other forms of gray literature.
4. Studies that did not provide appropriate data for analysis.
5. Studies whose full text could not be obtained through public databases or other sources.

Data extraction

We independently extracted the following information from each eligible study using a pre-designed data extraction form: study characteristics (first author, publication year), population characteristics (age, gender, sample size), intervention characteristics (type, duration, frequency, cycles), and outcome measures. If data were missing, we emailed the corresponding author up to three times within 3 weeks to obtain the relevant data. Two reviewers (GS and BW) performed data extraction independently, verified and adjudicated by a third reviewer (LD). Any disagreements were resolved through discussion and consensus.

Measures of treatment effect

This meta-analysis assessed the intervention effect using the Mean Difference (MD) and its standard deviation (SD) change. If the original studies did not directly report the SD, we estimated it based on standard error (SE), 95% confidence interval (95%CI), p-value, or t-statistics [25]. For studies that did not report the SD of pre-post changes, the following formula was used to estimate it:

$$SD_{change} = \sqrt{SD^2_{baseline} + SD^2_{Post} - 2 \times r \times SD_{baseline} \times SD_{post}}$$

The SD of the differences before and after the intervention was calculated, assuming a correlation coefficient of 0.5. This assumption, widely used in the literature, represents moderate measurement consistency, aiming to balance potential variability before and after the intervention and ensure the robustness and reliability of the analysis results [25].

Quality and GRADING of evidence assessment

The risk of bias was assessed using the Cochrane Risk of Bias tool (version 2.0), covering domains such as random sequence generation, allocation concealment, blinding, incomplete outcome data, and selective reporting of outcomes [26]. The overall risk of bias for each study was categorized as follows: Low risk of bias: All domains assessed as low risk; High risk of bias: At least one domain evaluated as high risk; Some concerns: If the study did not meet the above standards. Two independent reviewers performed the risk of bias assessment, and any disagreements were resolved through consultation and consensus.

The quality of the evidence was evaluated using the GRADE (Grading of Recommendations Assessment, Development, and Evaluation) approach, completed through the GRADEpro GDT online tool (www.gradepro.org). According to the GRADE framework, evidence quality was systematically assessed based on five domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. The quality of evidence for each outcome was classified as "high," "moderate," "low," or "very low," based on a comprehensive evaluation of the credibility of effect estimates [27]. Independent reviewers carried out all assessments, with disagreements resolved through discussion.

Statistical analysis

A meta-analysis was performed when two or more relatively homogeneous studies reported the same outcome measure [28]. The intervention effect was assessed using the MD and its 95% CI. The MD was calculated as the change in the intervention group before and after the intervention relative to the change in the control group and standardized based on the SD after the intervention to improve comparability between studies. To address possible variations between studies, a random-effects model was utilized, incorporating variations in study populations, interventions, and measurement methods [29]. Heterogeneity was assessed using the I^2 statistic and interpreted as follows: <25% indicating low heterogeneity, 25–75% indicating moderate heterogeneity, and >75% indicating high heterogeneity [30]. Publication bias was evaluated using funnel plots and Egger's test, with $p < 0.05$ considered indicative of significant bias [31]. When publication bias was detected, the trim and fill method was applied to adjust the pooled effect size and estimate the impact of missing studies [32].

To explore potential factors contributing to heterogeneity, we conducted subgroup analyses and evaluated the effects of different doses of TCEs on individuals with prediabetes. The subgroup analyses were based on the following pre-defined variables: intervention duration (short-term: ≤3 months; medium-term: 3–12 months; long-term: ≥12 months), exercise frequency (≤3 times/week; >3 times/week), duration of each exercise session (≤30 min; 30–60 min; ≥60 min), TCE type (e.g., Baduanjin, Yijinjing, Shaolin Neigong, Tai Chi), and whether the intervention was supervised. For outcomes with high heterogeneity, sensitivity analysis was conducted by excluding one study at a time to assess the robustness of the results and identify potential sources of heterogeneity. When subgroup analysis could not sufficiently explain heterogeneity, we performed meta-regression analysis to quantify the impact of possible confounding factors on the effect size and explore the sources of heterogeneity. According to the requirements of regression analysis, each covariate should include at least ten studies [25]. In this study, the pre-defined covariates included publication year, baseline BMI, sample size, and the proportion of males to systematically assess these variables' impact on the effect size and supplement the unexplained sources of heterogeneity from the subgroup analysis.

All statistical analyses were performed using Stata software (version 17.0; StataCorp, College Station, TX, USA), and forest plots were used to visually present the combined effect size and its confidence intervals. The statistical significance level was set at $p < 0.05$.

Results

Literature selection and study characteristics

The systematic search identified 213 potential records. After removing duplicates, 89 records remained for title and abstract screening. Thirty-two studies were selected for full-text assessment during the title and abstract screening. Following a thorough review of the full texts, 15 studies were finally included in this systematic review and meta-analysis. The literature selection and inclusion process is detailed in Fig. 1.

All included studies were published between 2010 and 2023, with varying study sizes, durations, and intervention types. The 15 studies included 35 experimental groups (926 participants) and 22 control groups (713 participants). Of these studies, 15 reported FBG, 11 reported HbA1c, and 12 reported 2hPG. 5 studies reported primary and secondary outcomes (TC, TG, HDL, and LDL). Detailed characteristics of the included studies are shown in Table 2.

Risk of bias, certainty of evidence

The risk of bias for each study is detailed in Appendix 3. Overall, two studies (13.3%) were classified as low risk of bias, twelve studies (80%) were classified as unclear risk of bias, and one study (6.7%) was classified as high risk of bias (Fig. 2). Regarding the randomization process, all studies clearly described the random sequence generation process; however, only two studies mentioned allocation concealment, and the remaining studies did not provide relevant information. Therefore, most studies in this area were rated as "unclear risk." Regarding outcome data missingness, one study was considered to have a "high risk of bias" due to a high attrition rate and lack of reporting on the reasons for attrition, which could be related to the actual outcomes.

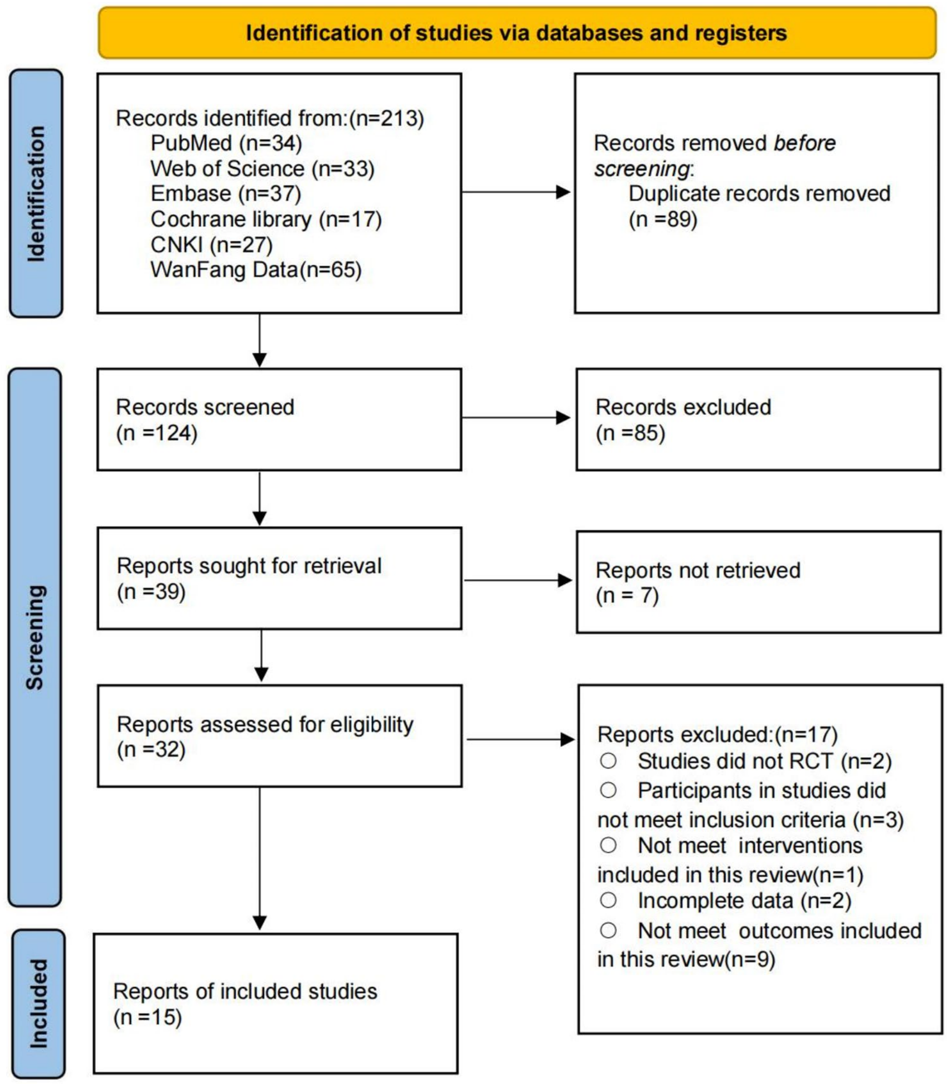

Fig. 1 PRISMA flow diagram of the search process for studies

Additionally, four studies were rated as "unclear risk" due to incomplete information on dropout rates. In contrast, the remaining studies were assessed as having a "low risk of bias" in this domain. For other sources of bias, none of the studies indicated additional bias sources. Thus, they were all rated as "low risk of bias."

After evaluating the quality of evidence using the GRADE framework, the quality of evidence for all outcomes was determined to be low to moderate (Table 3). This result was mainly influenced by the higher risk of bias in some studies. Furthermore, the heterogeneity between studies also somewhat reduced the overall credibility of the evidence.

Primary outcomes

A total of 27 studies involving 1,190 participants reported changes in HbA1c (Fig. 3). The meta-analysis showed that TCEs significantly reduced HbA1c levels in individuals with prediabetes (MD = -0.28%; 95% CI: -0.38% to -0.18%; P = 0.001). Heterogeneity analysis indicated moderate heterogeneity between studies (I2 = 53.1%).

A total of 35 studies involving 1,831 participants reported changes in FBG (Fig. 4). The meta-analysis showed that TCEs significantly reduced FBG levels in individuals with prediabetes (MD = -0.44 mmol/L; 95% CI: -0.53 to -0.34 mmol/L; $P < 0.001$). Heterogeneity analysis indicated low heterogeneity between studies (I^2 = 21.6%).

A total of 26 studies involving 1,092 participants reported changes in 2hPG (Fig. 5). The meta-analysis showed that TCEs significantly reduced 2hPG levels in individuals with prediabetes (MD = -1.16 mmol/L; 95% CI: -1.48 to -0.85 mmol/L; $P < 0.001$). Heterogeneity

Table 2 Basic characteristics of the included studies

Author Year	Group	Sample Size (F/M)	Age (Mean ± SD)	Supervised Status	Duration per Session	Exercise Period	Exercise Frequency	Results
Wang et al. 2010 [33]	Yijinjing	26/34	25 ~ 30	supervised	20	12	7	Significant changes:b,c
	Con							
Song et al. 2013 [34]	Tai Chi	21/19	54	unsupervised	50	12	7	Significant changes: a,b,c
	Con	21/19	54					
Fang et al. 2014 [35]	Baduanjin	14/16	56.62 ± 8.85	unsupervised	60	12	5	Significant changes: a,b,c,d,e,g
	Con	13/17	57.13 ± 9.26					No significant changes:f
Wu et al. 2015 [36]	Shaolin Neigong	12/8	54.50 ± 12.15	unsupervised	45	12	5	Significant changes: a,b,c
	Con	12/9	56.25 ± 12.42					
Wu et al. 2016 [37]	Baduanjin	20	57. 75 ± 8. 78	unsupervised	15	12	5	Significant changes: a,b,c
		20	63. 25 ± 6. 86		30	12	5	
		20	60. 38 ± 4. 81		45	12	5	
	Con	20	60. 38 ± 5. 81					
Li et al. 2017 [38]	Shaolin Neigong	7/3	61.70 ± 9.96	unsupervised	15	24	5	Significant changes: a,b,c
		8/2	55.20 ± 9.32		30	24	5	
		5/5	61.70 ± 10.33		45	24	5	
		7/3	60.50 ± 11.37		60	24	5	
	Con	5/5	57.10 ± 12.59					
Li et al. 2019a [39	Tai Chi	31/12	55.72 ± 3.42	supervised	60	16	5	Significant changes:c
	Con	29/15	55.25 ± 3.38					
Li et al. 2019b [40	Baduanjin	34/15	56.90 ± 3.94	unsupervised	20	36	3	Significant changes:c
	Con	33/14	56.34 ± 4.03					
Li et al. 2019c [41	Baduanjin	23/6	57.41 ± 3.38	unsupervised	20	24	3	Significant changes: a,c
	Con	21/6	55.81 ± 4.09					
Li et al. 2020 [42]	Baduanjin	33/27	57.42 ± 5.55	supervised	60	24	5	Significant changes: a,b,c
	Con	32/23	58.89 ± 5.22					
Hu et al. 2022 [43]	Tai Chi	19	62.68 ± 7.33	supervised	50	12	4	Significant changes: a,b,c,d,g
	Con	19	61.58 ± 6.62					No significant changes:e,f
Ma et al. 2022 [44]	Baduanjin	18/16	59.18 ± 3.93	supervised	45	48	2	Significant changes: a,b,c,d,e,f,g
	Con	18/14	59.09 ± 5.25					
Cai et al. 2023 [45]	Yijinjing	9/8	63.41 ± 5.06	supervised	60	24	5	Significant changes:c,d,e,f
	Con	12/5	61.82 ± 4.33					No significant changes: a,b,g
Zhang et al. 2023 [46]	Yijinjing	18/7	61.12 ± 6.57	supervised	60	24	5	Significant changes:b
	Con	17/8	63.00 ± 4.72					No significant changes: a, c,d,e,f,g
Fu et al. 2023 [47]	The Six-Step Meridian Guiding Technique	8/4	52.1 ± 10.2	unsupervised	24	2	7	Significant changes:b,c
	Con	5/5	58.4 ± 3.9					

a, HbA1c; b, 2hPG; c, FBG; d, TC; e, TG; f, HDL; g, LDL; Con, Control

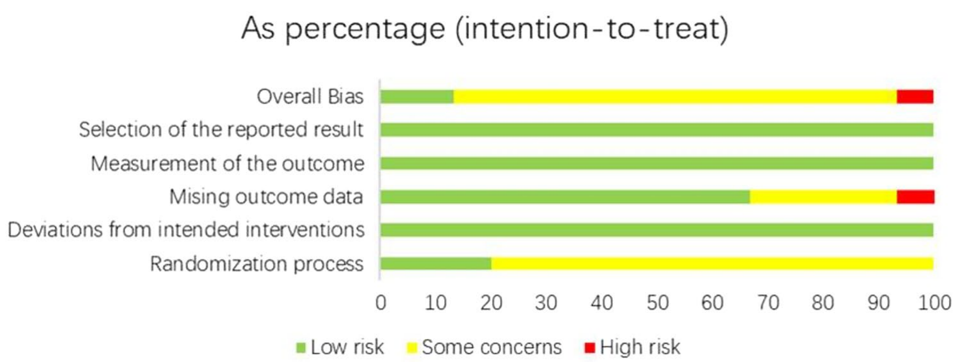

Fig. 2 The overall risk of bias is presented as a percentage of each risk of bias item across all included studies. Green = Low risk, Red = High risk, Yellow = Some concerns

analysis indicated moderate heterogeneity between studies (I^2 = 64.2%).

Secondary outcomes

Seven studies involving 370 participants reported changes in TC, TG, HDL, and LDL. The meta-analysis results showed that TCEs significantly reduced TC (MD = -0.31 mmol/L; 95% CI: -0.50 to -0.11 mmol/L; $P = 0.002$; I^2 = 0%) and TG (MD = -0.28 mmol/L; 95% CI: -0.50 to -0.06 mmol/L; $P = 0.012$; I^2 = 53.4%) in individuals with prediabetes(Figs. 6).

However, TCEs did not show statistically significant improvements in HDL (MD = -0.28 mmol/L; 95% CI: -0.50 to -0.06 mmol/L; $P = 0.012$; I^2 = 85.6%) and LDL (MD = 0.16 mmol/L; 95% CI: -0.04 to 0.35 mmol/L; $P = 0.12$; I^2 = 52.0%) in prediabetes patients(Figs. 6).

Subgroup analysis

Subgroup analyses were performed based on pre-defined variables: intervention duration (short-term: ≤3 months; medium-term: 3–12 months; long-term: ≥12 months), exercise frequency (≤ 3 times/week; >3 times/week), duration of each exercise session (≤ 30 min; 30–60 min; ≥60 min), TCE type (e.g., Baduanjin, Yijinjing, Shaolin Neigong, and Tai Chi), and supervision status (supervised, non-supervised), as detailed in Appendix 4 and Table 4.

The subgroup analysis showed that intervention duration significantly impacted the improvement of HbA1c (subgroup difference $P = 0.047$) and FBG (subgroup difference $P = 0.044$). TCE interventions lasting ≥ 12 months had the most significant effect, with improvements in HbA1c and FBG significantly better than those with short-term (≤ 3 months) or medium-term (3–12 months) interventions. Further analysis revealed that 2hPG ($P < 0.001$) showed significant improvements across all intervention durations, while interventions lasting ≥ 12 months demonstrated significant effects on TC ($P = 0.002$) and TG ($P < 0.001$).

Exercise frequency significantly improved LDL levels (subgroup difference $P = 0.043$), with TCE interventions of ≤ 3 times/week showing significantly better effects than > 3 times/week. Further analysis indicated that HbA1c ($P < 0.001$), FBG ($P < 0.001$), and 2hPG ($P < 0.001$) showed significant improvements across all frequencies, while improvements in TC ($P = 0.004$) and TG ($P = 0.001$) were only observed at an exercise frequency of ≤ 3 Times/week. Additionally, the study found that TCE interventions > 3 times/week did not significantly improve lipid profiles.

The duration of each exercise session significantly improved FBG (subgroup difference $P = 0.036$), 2hPG (subgroup difference $P = 0.017$), and LDL (subgroup difference $P = 0.018$), with interventions lasting ≤ 60 min showing more significant effects. Further analysis revealed that FBG and 2hPG showed significant improvements across all durations, while interventions lasting ≥ 60 min did not show significant effects on HbA1c. Additionally, interventions lasting 30–60 min showed significant improvements in TC ($P = 0.002$), TG ($P = 0.012$), and LDL ($P = 0.018$), while interventions lasting ≥ 60 min did not show significant effects on lipid profiles.

Supervision status significantly affected the improvement of 2hPG (subgroup difference $P = 0.001$), with non-supervised TCE interventions showing better effects than supervised ones. However, regardless of supervision, TCE interventions significantly improved blood glucose levels.

Different TCE types showed significant differences in the improvement of HbA1c (subgroup difference $P = 0.003$), 2hPG (subgroup difference $P < 0.001$), TG (subgroup difference $P = 0.012$), and LDL (subgroup difference $P = 0.019$). Specifically, Shaolin Neigong showed the most significant improvement in HbA1c ($P = 0.003$), Tai Chi showed the most potent effect on 2hPG ($P < 0.001$), and Baduanjin showed clear advantages in improving TG and LDL ($P = 0.012$). Additionally,

Table 3 GRADE summary of evidence

Certainty assessment							№ of patients		Effect		Certainty	Importance
№ of studies	**Study design**	**Risk of bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Other considerations**	**TCEs**	**Con**	**Relative (95% CI)**	**Absolute (95% CI)**		
FBG												
35	randomised trials	serious	not serious	not serious	not serious	none	916	905	-	MD **0.43 mmol/L lower** (0.53 lower to 0.34 lower)	⊕⊕⊕○ **Moderate**	
HbA1c												
27	randomised trials	serious	serious	not serious	not serious	none	598	592	-	MD **0.28 mmol/L lower** (0.38 lower to 0.18 lower)	⊕⊕○○ **Low**	
2hPG												
26	randomised trials	serious	serious	not serious	not serious	none	550	542	-	MD **1.16 mmol/L lower** (1.48 lower to 0.85 lower)	⊕⊕○○ **Low**	
TC												
7	randomised trials	serious	not serious	not serious	not serious	none	188	182	-	MD **0.31 mmol/L lower** (0.5 lower to 0.11 lower)	⊕⊕⊕○ **Moderate**	
TG												
7	randomised trials	serious	not serious	not serious	not serious	none	188	182	-	MD **0.28 mmol/L lower** (0.5 lower to 0.06 lower)	⊕⊕○○ **Moderate**	
HDL												
7	randomised trials	serious	very serious	serious	not serious	none	188	182	-	MD **0.16 mmol/L higher** (0.04 lower to 0.35 higher)	⊕○○○ **Very low**	
LDL												
7	randomised trials	serious	not serious	not serious	not serious	none	188	182	-	MD **0.18 mmol/L lower** (0.42 lower to 0.06 higher)	⊕⊕⊕○○ **Moderate**	

CI: confidence interval; **MD**: mean difference

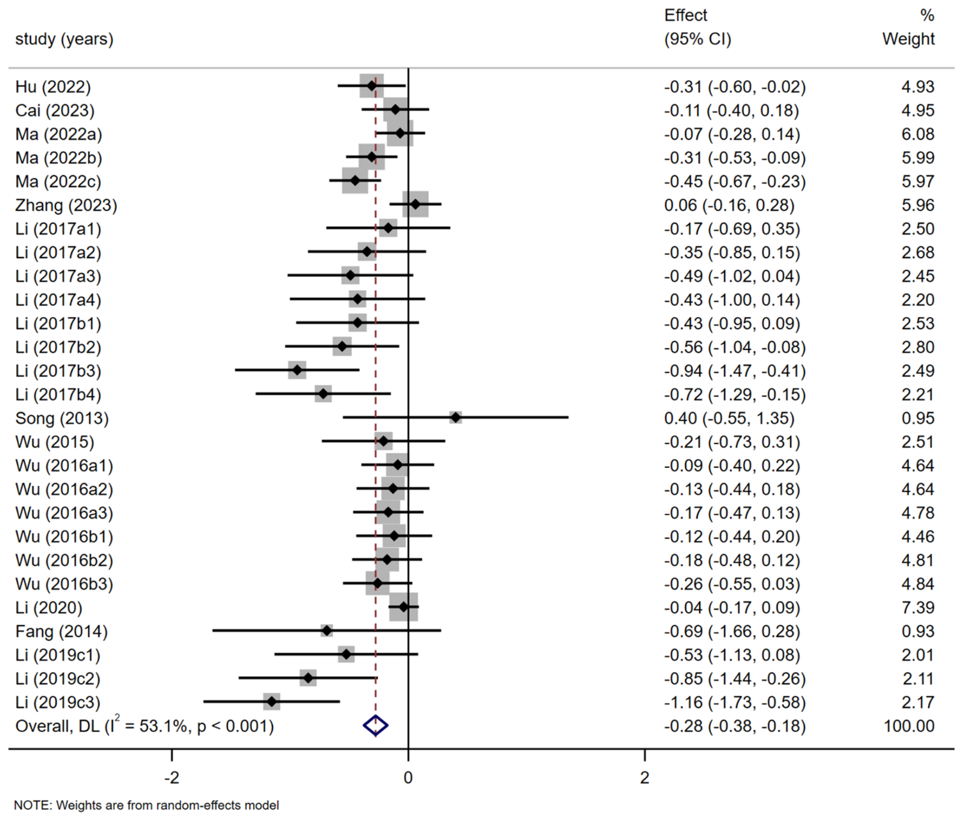

Fig. 3 Forest plot of the effect of TCEs versus control groups on HbA1c

Baduanjin showed significant effects in the comprehensive improvement of blood glucose and lipid profiles.

In summary, subgroup analysis identified intervention duration (≥ 12 months), frequency (≤ 3 times per week), session duration (30–60 min), and supervision status (non-supervised) as key factors influencing glycemic and lipid outcomes. Among the TCE types, Baduanjin exhibited the most significant effects on lipid parameters, particularly TG and LDL. At the same time, Shaolin Neigong and Tai Chi demonstrated the greatest improvements in glycemic outcomes, including HbA1c and 2hPG.

Results of meta-regression

A meta-regression analysis assessed the sources of heterogeneity and the potential impact of confounding factors on effect estimates, ensuring that each covariate included at least ten studies, as detailed in Appendix 5. The confounders included publication year, mean age, male proportion, BMI, and sample size. The regression analysis showed that the improvement in 2hPG was significantly associated with sample size (β = -0.018; 95% CI: -0.0291 to -0.0069). No significant associations were found between the confounding factors and other outcomes (such as HbA1c, FBG, TC, TG, HDL, and LDL).

Sensitivity analysis

To evaluate the impact of each study on the overall effect estimates and the variability of the results, a sensitivity analysis was conducted by systematically removing one study at a time, as detailed in Appendix 9. This approach assessed the reliability of the findings. The analysis revealed that the overall effect sizes and their 95% confidence intervals changed only slightly, while the direction of the effect remained consistent across all outcomes.

The study Ma2022c [35] was identified as the primary contributor to the heterogeneity observed in the HDL outcome. When this study was included, heterogeneity was significant (I^2 = 85.6%, $P < 0.001$); however, its removal resulted in a marked decrease in heterogeneity to 0% (I^2 = 0.0%, $P = 0.483$). Additionally, the summary effect size changed slightly from 0.16 (95% CI: -0.04 to 0.35) to 0.07 (95% CI: -0.01 to 0.15), with the overall trend and direction of the effect remaining consistent. Although some outcomes exhibited high heterogeneity, the influence of individual studies on the overall results was limited, indicating that the conclusions of this meta-analysis are robust and reliable.

Publication bias

Egger's test for publication bias revealed that 2hPG ($P = 0.023$) and HbA1c ($P = 0.001$) showed evidence of

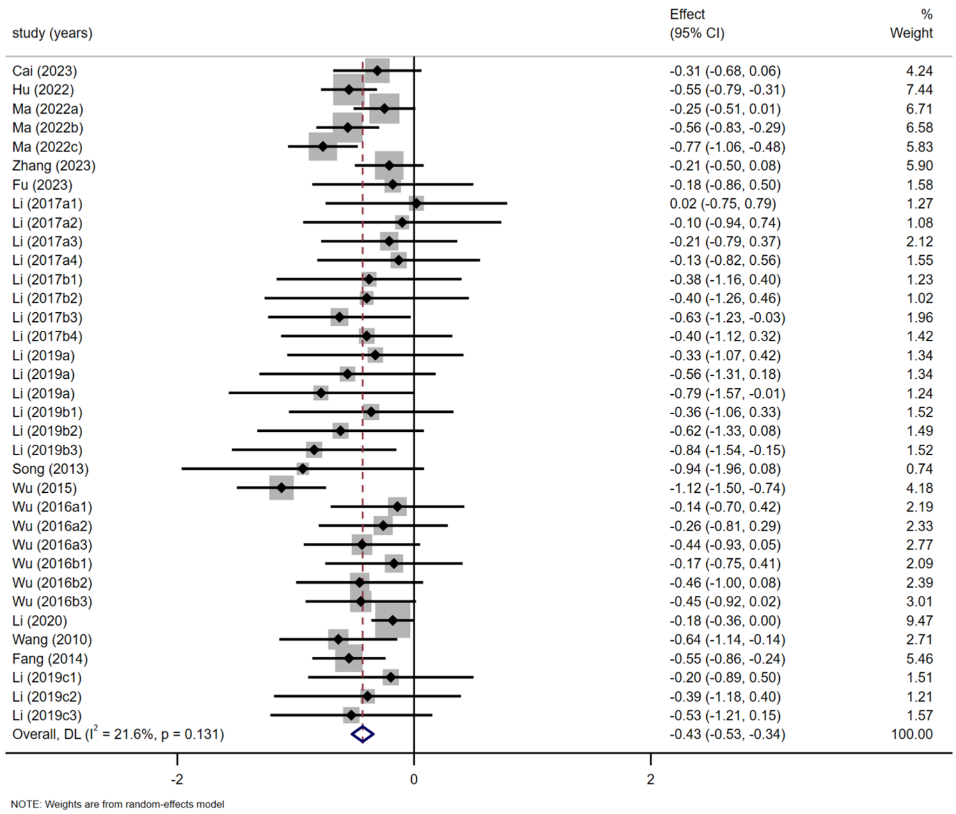

Fig. 4 Forest plot of the effect of TCEs versus control groups on FBG

publication bias, while FBG ($P = 0.66$), TC ($P = 0.429$), TG ($P = 0.177$), HDL ($P = 0.717$), and LDL ($P = 0.177$) showed no evidence of publication bias, as detailed in Appendix 6 and 7. The trim and fill method was applied to adjust the 2hPG and HbA1c outcomes, showing publication bias. After adjustment, no additional studies were missing, and the adjusted effect sizes were consistent with the original results (2hPG: $P = 0.00$; HbA1c: $P = 0.00$), indicating that the original analysis results are robust and unaffected by potential publication bias, as detailed in Appendix 8.

Adverse events

None of the included randomized controlled trials reported adverse events related to the intervention. Therefore, no information on adverse events could be extracted from the existing literature for this study.

Discussion

This study assessed the comprehensive effects of various TCEs on blood glucose and lipid control in individuals with prediabetes through systematic review and meta-analysis. We also explored the potential moderating effects of intervention duration, intensity, and frequency through subgroup analysis. Although current guidelines generally recommend exercise as an essential component of diabetes prevention and management, adherence to and effectiveness of traditional unsupervised exercise interventions are often limited due to the close association between diabetes and physical inactivity. To address this, we specifically analyzed the differences between supervised and unsupervised exercise forms to explore further the applicability of TCEs in managing prediabetes. The results indicate that TCEs, as a simple and highly acceptable form of exercise, show significant health benefits even in an unsupervised setting. Based on these findings, we suggest that individuals with prediabetes adopt TCEs as an ideal intervention for lifestyle management to foster long-term exercise habits and improve glucose and lipid metabolism.

TCEs are low-intensity aerobic exercises that combine body movement, mental focus, and breath regulation ("three-in-one"), with metabolic improvement effects comparable to or even better than moderate-intensity aerobic exercise [35, 38, 47]. The primary mechanism of TCEs is to enhance insulin sensitivity and improve skeletal muscle glucose uptake [48]. However, this process's higher dependency on insulin signaling and lower efficiency require longer intervention durations to achieve significant effects [48]. Compared to traditional aerobic exercise, TCEs show more pronounced effects in improving mental health [43, 44]. Previous studies have confirmed that psychological regulation also positively

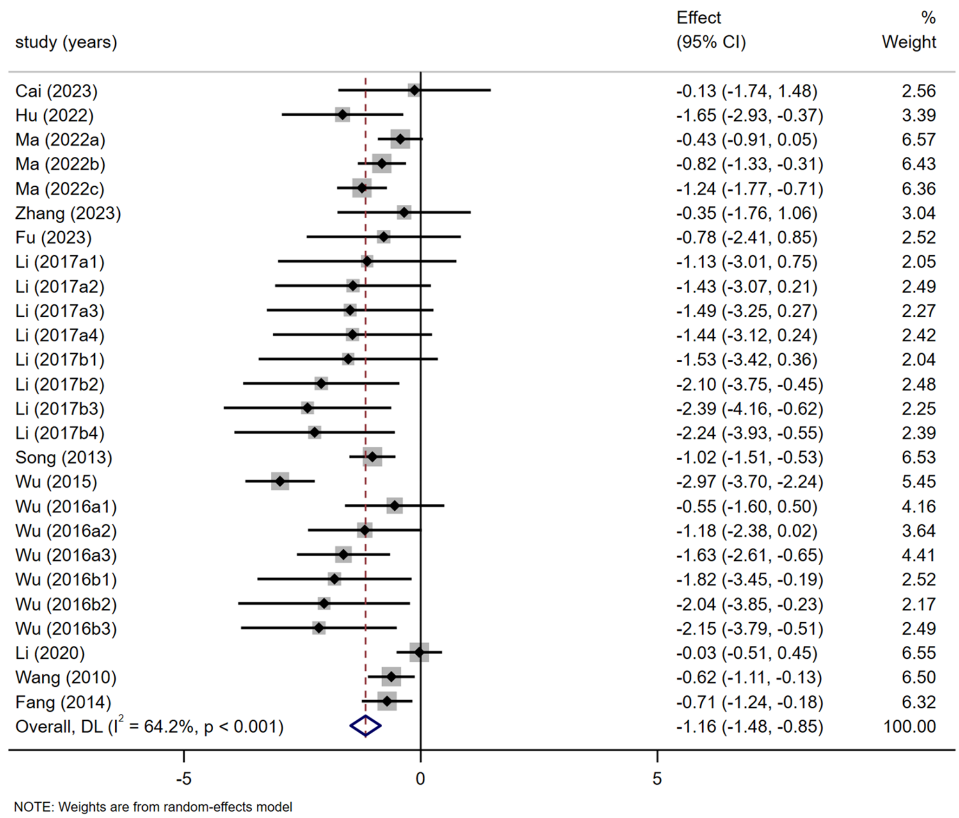

Fig. 5 Forest plot of the effect of TCEs versus control groups on 2hPG

affects blood glucose control [49]. TCEs, through mindful practice and "breathing with the mind," regulate the balance of cortical excitation and inhibition, promoting mental focus and calm, which helps lower stress hormones like cortisol [50]. Reduced cortisol levels improve insulin sensitivity and glucose utilization, further improving blood glucose levels [51].

Moreover, Li et al. [39, 40] studies have shown that resistance training significantly outperforms Baduanjin in lowering FBG and HbA1c. This difference may be due to the different metabolic regulatory mechanisms of the two types of exercise. Resistance exercise directly consumes glucose reserves through high-intensity muscle contractions, induces muscle hypertrophy, and increases muscle glucose utilization ability [52]. This mechanism significantly improves blood glucose quickly, reflecting higher metabolic regulation efficiency. However, concerns arose as 4 and 6 participants dropped out from resistance training groups in two studies due to severe muscle soreness and discomfort. In contrast, multiple studies from China [33, 39, 40] and Boston [53–55] have shown that TCEs have higher adherence and acceptance, with patients reporting more positive subjective experiences, including greater enjoyment [53–55], energy levels [33, 35], and improved quality of life [45, 56].

Interestingly, we found that participants practicing TCEs in unsupervised settings showed more significant improvements in blood glucose levels. TCEs, through slow, smooth, and rhythmic body movements, mental regulation, and controlled breathing, help practitioners enter a meditative state during exercise [57]. Unsupervised practice aligns with the Daoist philosophy of "following the natural way," allowing practitioners to follow their rhythm and manner, naturally exploring the mind-body connection and maximizing autonomy [58]. Moreover, most of the studies included in this meta-analysis were conducted in China, where collective exercise is deeply rooted in the culture. TCEs are often practiced in public spaces (e.g., parks or squares), where mutual encouragement and social support further enhance internal motivation, prompting patients to engage more actively in exercise and achieve sustained health benefits [59]. This sense of social belonging may be the key to maintaining high participation and significant health improvements in unsupervised settings among Chinese practitioners. Two studies from Boston [55, 60] also indicated that social support positively impacts Western practitioners. In these studies, participants improved exercise adherence through group practices and social interaction, improving health outcomes. This finding suggests that the collective exercise model represented

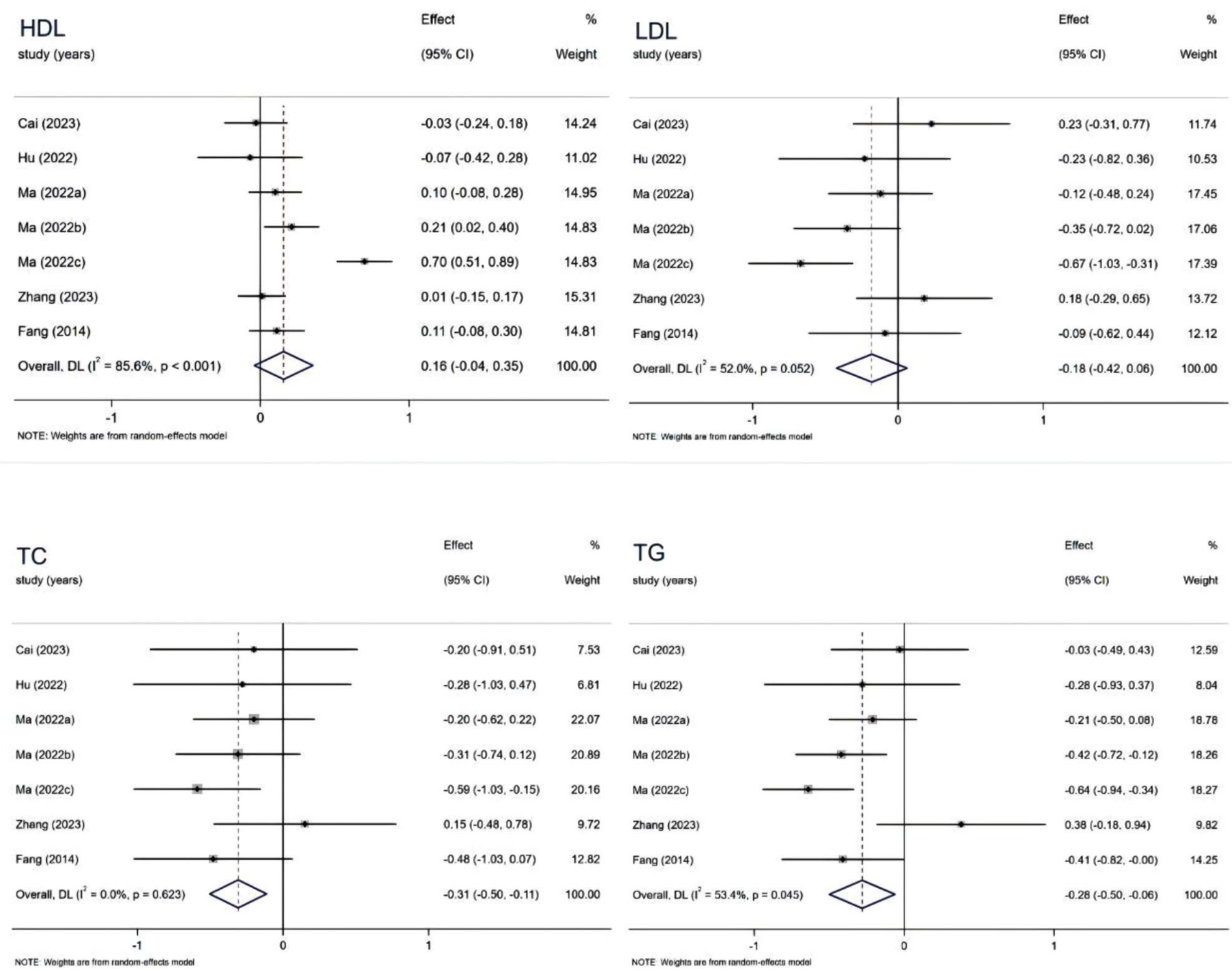

Fig. 6 Forest plot of the effect of TCEs versus control groups on lipid metabolism (TC, TG, HDL, LDL)

by TCEs aligns well with Chinese culture and has cross-cultural potential. Despite cultural differences in social support mechanisms, the sense of community and motivational support from collective exercise generally facilitates long-term participation. It improves health, further supporting the feasibility and effectiveness of TCEs as a global health intervention strategy.

The dyslipidemia pattern in prediabetes is similar to that in T2D, characterized by low HDL levels, elevated TG levels (hypertriglyceridemia), and an increase in small, dense LDL particles [61]. These lipid abnormalities reflect worsening metabolic disturbances and indicate that individuals with prediabetes may have a higher cardiovascular risk. Thus, this study included lipid metabolism indicators as secondary outcomes to assess the metabolic attributes of prediabetes comprehensively. Among all lipid indicators, TG is the most significantly associated risk factor for prediabetes, primarily controlled through lifestyle interventions [62]. This meta-analysis found that TCEs significantly improved TG levels, consistent with Dong et al. [42] and Song et al. [42]. However, no significant improvements in HDL and LDL were observed. To explore this phenomenon further, we conducted a subgroup analysis. The results suggested that compared to TG, HDL and LDL require longer durations of an exercise intervention to show improvement, consistent with findings from Pan et al. [63]. This was further supported by Ma et al. [35], who found that Baduanjin requires more than 6 months of continuous intervention to improve HDL levels significantly. Furthermore, with extended intervention durations, Baduanjin significantly outperformed traditional aerobic exercise in improving HDL. Therefore, in the long term, Baduanjin may have advantages over conventional aerobic exercise in improving lipid metabolism and blood glucose control. Additionally, two network meta-analyses have demonstrated that Baduanjin outperforms other forms of TCEs in improving HDL levels [64, 65]. This suggests that the unique mechanisms of each TCE modality—ranging from respiratory regulation to enhanced

Table 4 Summary of subgroup analysis results

Outcome	Number of participants	Heterogeneity		Meta-analysis		Subgroup differences
		P value	I^2	Effect estimate (95%CI)	*P* value	
Meta-analysis results by exercise period						
HbA1c(%)	1190	0.001*	53.10%	-0.28(-0.38,-0.18)	0.001*	0.047*
≤ 3 months	474	0.765	0.00%	-0.19(-0.29,-0.08)	< 0.001*	
3–12 months	590	< 0.001*	73.10%	-0.34(-0.50,-0.17)	< 0.001*	
≥ 12 months	126	0.635	0.00%	-0.46(-0.68,-0.29)	< 0.001*	
FBG(mmol/L)	1831	0.131	21.60%	-0.44(-0.53,-0.34)	< 0.001*	0.044*
≤ 3 months	619	0.073	37.20%	-0.39(-0.56,-0.22)	< 0.001*	
3–12 months	1076	0.68	0.00%	-0.37(-0.47,-0.26)	< 0.001*	
≥ 12 months	126	0.313	1.70%	-0.67(-0.88,-0.45)	< 0.001*	
2hPG (mmol/L)	1092	< 0.001*	64.20%	-1.16(-1.48,-0.85)	< 0.001*	0.663
≤ 3 months	436	< 0.001*	69.50%	-1.31(-1.84,-0.78)	< 0.001*	
3–12 months	530	0.007	57.10%	-1.06(-1.54,-0.58)	< 0.001*	
≥ 12 months	126	0.166	47.90%	-0.98(-1.50,-0.46)	< 0.001*	
TC (mmol/L)	370	0.623	0.00%	-0.31(-0.50,-0.11)	0.002*	0.24
≤ 3 months	94	0.855	0.00%	-0.22(-0.58,0.15)	0.238	
3–12 months	150	0.491	0.00%	-0.17(-0.49,0.15)	0.289	
≥ 12 months	126	0.757	0.00%	-0.55(-0.89,-0.21)	0.002*	
TG (mmol/L)	370	0.045*	53.40%	-0.28(-0.50,-0.06)	0.012*	0.078
≤ 3 months	94	0.848	0.00%	-0.22(-0.49,0.05)	0.103	
3–12 months	150	0.037*	69.70%	-0.07(-0.53,0.38)	0.759	
≥ 12 months	126	0.375	0.00%	-0.56(-0.80,-0.31)	< 0.001*	
HDL (mmol/L)	370	< 0.001*	85.60%	0.16(-0.04,0.35)	0.12	0.526
≤ 3 months	94	0.399	0.00%	0.07(-0.09,0.23)	0.424	
3–12 months	150	0.167	44.10%	0.07(-0.08,0.21)	0.371	
≥ 12 months	126	< 0.001*	94.90%	0.41(-0.17,0.98)	0.17	
LDL (mmol/L)	370	0.052	52.00%	-0.18(-0.42,0.06)	0.144	0.525
≤ 3 months	94	0.755	0.00%	-0.15(-0.46,0.16)	0.339	
3–12 months	150	0.106	55.50%	-0.02(-0.41,0.38)	0.942	
≥ 12 months	126	0.074	68.70%	-0.41(-0.98,0.15)	0.152	
Meta-analysis results by exercise frequency						
HbA1c(%)	1190	0.001*	53.10%	-0.28(-0.38,-0.18)	< 0.001*	0.069
≤ 3 times/week	378	0.003*	72.50%	-0.47(-0.72,-0.2)	< 0.001*	
> 3 times/week	812	0.064	34.20%	-0.21(-0.31,-0.11)	< 0.001*	
FBG(mmol/L)	1831	0.131	21.60%	-0.44(-0.53,-0.34)	< 0.001*	0.296
≤ 3 times/week	666	0.346	10.70%	-0.51(-0.66,-0.35)	< 0.001*	
> 3 times/week	1155	0.145	23.00%	-0.41(-0.52,-0.30)	< 0.001*	
2hPG (mmol/L)	1092	< 0.001*	64.20%	-1.16(-1.48,-0.85)	< 0.001*	0.143
≤ 3 times/week	198	0.081	60.20%	-0.82(-1.28,-0.36)	< 0.001*	
> 3 times/week	894	< 0.001*	65.40%	-1.27(-1.65,-0.88)	< 0.001*	
TC (mmol/L)	370	0.623	0.00%	-0.31(-0.50,-0.11)	0.002*	0.494
≤ 3 times/week	198	0.524	0.00%	-0.36(-0.61,-0.12)	0.004*	
> 3 times/week	172	0.429	0.00%	-0.22(-0.54,0.10)	0.181	
TG (mmol/L)	370	0.045	53.40%	-0.28(0.50,-0.06)	0.012*	0.138
≤ 3 times/week	198	0.135	50.00%	-0.42(-0.67,-0.18)	0.001*	
> 3 times/week	172	0.148	43.90%	-0.10(-0.44,0.24)	0.547	
HDL (mmol/L)	370	< 0.001*	85.60%	0.16(-0.04,0.35)	0.12	0.102
≤ 3 Times/Week	198	< 0.001*	91.40%	0.34(-0.03,0.70)	0.068	
> 3 Times/Week	172	0.711	0.00%	0.02(-0.08,0.13)	0.642	
LDL (mmol/L)	370	0.052	52.00%	-0.18(-0.42,0.06)	0.144	0.043*
≤ 3 Times/Week	198	0.103	56.00%	-0.38(-0.70,-0.07)	0.018*	
> 3 Times/Week	172	0.603	0.00%	-0.04(-0.22,0.31)	0.748	
Meta-analysis results by single exercise session duration						

Table 4 (continued)

Outcome	Number of participants	Heterogeneity		Meta-analysis		Subgroup differences
		P value	I^2	Effect estimate (95%CI)	*P* value	
HbA1c(%)	1190	0.001*	53.10%	-0.28(-0.38,-0.18)	< 0.001*	0.243
≤ 30 minutes	420	0.045	46.40%	-0.34(-0.52,-0.17)	< 0.001*	
30–60 minutes	466	0.08	41.60%	-0.30(-0.43,-0.16)	< 0.001*	
≥ 60 minutes	304	0.084	48.50%	-0.14(-0.32,0.05)	0.141	
FBG(mmol/L)	1821	0.131	21.60%	-0.44(-0.53,-0.34)	< 0.001*	0.036*
≤ 30 minutes	790	0.976	0.00%	-0.33(-0.51,0.16)	< 0.001*	
30–60 minutes	446	0.032*	50.80%	-0.57(-0.75,-0.40)	< 0.001*	
≥ 60 minutes	615	0.474	0.00%	-0.31(-0.42,-0.19)	< 0.001*	
2hPG (mmol/L)	1092	< 0.001*	64.20%	-1.164(-1.48,-0.85)	< 0.001*	0.017*
≤ 30 minutes	262	0.819	0.00%	-1.25(1.76,-0.75)	< 0.001*	
30–60 minutes	466	< 0.001*	77.20%	-1.45,(-1.97,-0.93)	< 0.001*	
≥ 60 minutes	364	0.124	40.10%	-0.57(-0.98,-0.16)	0.007*	
TC (mmol/L)	370	0.623	0.00%	-0.31(-0.50,-0.11)	0.002*	0.505
30–60 minutes	226	0.629	0.00%	-0.35(-0.59,-0.12)	0.003*	
≥ 60 minutes	114	0.331	9.50%	-0.20(-0.58,0.17)	0.29	
TG (mmol/L)	370	0.045	53.40%	-0.28(0.50,-0.06)	0.012*	0.15
30–60 minutes	226	0.245	27.80%	-0.41(-0.61,-0.20)	< 0.001*	
≥ 60 minutes	114	0.078	60.80%	-0.05(-0.49,0.38)	0.809	
HDL (mmol/L)	370	< 0.001*	85.60%	0.16(-0.04,0.35)	0.12	0.207
30–60 minutes	226	< 0.001*	89.20%	-0.25(-0.07,0.57)	0.127	
≥ 60 minutes	114	0.583	0.00%	0.03(-0.07,0.14)	0.547	
LDL (mmol/L)	370	0.052	52.00%	-0.18(-0.42,0.06)	0.144	0.018*
30–60 minutes	226	0.19	37.10%	-0.36(-0.61,-0.10)	0.006*	
≥ 60 minutes	114	0.659	0.00%	-0.11(-0.18,0.40)	0.461	
Meta-analysis results by supervised status						
HbA1c(%)	1190	0.001*	53.10%	-0.28(-0.38,-0.18)	< 0.001*	0.053
supervised	430	0.008*	65.50%	-0.17(-0.31,-0.03)	0.017*	
unsupervised	760	0.043*	38.20%	-0.35(-0.48,-0.22)	< 0.001*	
FBG(mmol/L)	1821	0.131	21.60%	-0.44(-0.53,-0.34)	< 0.001*	0.667
supervised	781	0.031*	49.60%	-0.43(-0.57.-0.28)	< 0.001*	
unsupervised	1041	0.486	0.00%	-0.47(-0.59,-0.35)	< 0.001*	
2hPG (mmol/L)	1092	< 0.001*	64.20%	-1.16(-1.48,-0.85)	< 0.001*	0.001*
supervised	490	0.032*	54.30%	-0.65(-0.99,-0.30)	< 0.001*	
unsupervised	602	0.008*	50.30%	-1.52(-1.93,-1.11)	< 0.001*	
Meta-analysis results for different types of TCEs						
HbA1c(%)	1190	0.001*	53.10%	-0.28(-0.38,-0.18)	< 0.001*	0.003*
Yijinjing	84	0.354	0.00%	-0(-0.18,0.17)	0.971	
Taiji	108	0.162	48.80%	-0.11(-0.74,0.52)	0.74	
Baduanjin	200	0.003*	59.10%	-0.26(-0.38,-0.13)	< 0.001*	
Shaolin Neigong	798	0.601	0.00%	-0.47(-0.65,-0.30)	< 0.001*	
FBG(mmol/L)	1799	0.117	23.00%	-0.44(-0.53,-0.35)	< 0.001*	0.425
Yijinjing	144	0.344	6.20%	-0.32(-0.54,-0.10)	0.004	
Taiji	369	0.873	0.00%	-0.57(-0.77,-0.36)	< 0.001*	
Baduanjin	1086	0.244	17.90%	-0.41(-0.52,-0.30)	< 0.001*	
Shaolin Neigong	200	0.053	47.80%	-0.44(-0.74,-0.13)	0.005*	
2hPG (mmol/L)	1070	< 0.001*	65.60%	-1.18(-1.50,-0.86)	< 0.001*	< 0.001*
Yijinjing	144	0.812	0.00%	-0.56(-1.0,-0.11)	0.015*	
Taiji	108	0.368	0.00%	-1.10(-1.55,-0.64)	< 0.001*	
Baduanjin	618	0.008*	58.20%	-0.89(-1.25,-0.53)	< 0.001*	
Shaolin Neigong	200	0.41	3.00%	-2.22(-2.70,-1.73)	< 0.001*	
TC (mmol/L)	342	0.494	0.00%	-0.31(-0.50,-0.11)	0.003*	0.155
Yijinjing	84	0.47	0.00%	-0(-0.47,0.47)	0.991	

Table 4 (continued)

Outcome	Number of participants	Heterogeneity		Meta-analysis		Subgroup differences
		P value	I^2	Effect estimate (95%CI)	*P* value	
Baduanjin	258	0.605	0.00%	-0.38(-0.60,-0.16)	0.001*	
TG (mmol/L)	342	0.025*	61.10%	-0.28(-0.52,-0.03)	0.026*	0.012*
Yijinjing	84	0.269	18.20%	-0.42(0.60,-0.23)	0.485	
Baduanjin	258	0.262	25.00%	0.14(-0.26,0.54)	< 0.001*	
HDL (mmol/L)	342	< 0.001*	87.40%	-0.18(-0.03,0.40)	0.089	0.068
Yijinjing	84	< 0.001*	0.00%	-0.01(-0.13,0.12)	0.943	
Baduanjin	258	0.768	89.10%	0.28(0.002,0.56)	0.048*	
LDL (mmol/L)	342	0.029*	60%	-0.17(-0.45,0.11)	0.225	0.019*
Yijinjing	84	< 0.001*	89.10%	-0.20(-0.15,0.56)	0.265	
Baduanjin	258	0.46	13.50%	-0.33(-0.60,-0.06)	0.016*	

HbA1c: glycated hemoglobin; FBG: fasting blood glucose; 2hPG: 2-hour plasma glucose; TC: total cholesterol; TG: triglycerides; HDL: high-density lipoprotein cholesterol; LDL: low-density lipoprotein cholesterol; CI: confidence interval, *P < 0.05

systemic circulation—may contribute differently to HDL improvement. Baduanjin, characterized by gentle stretching, coordinated breathing, and mental regulation, positively impacts HDL enhancement by improving autonomic nervous system balance and regulating hormone-sensitive lipase activity [66]. In contrast, Yijinjing, which combines dynamic and static exercises with an emphasis on strength-focused practices, improves overall metabolic activity but has relatively limited effects on HDL levels [67]. In this study, Baduanjin demonstrated significant improvements in both glycemic and lipid profiles. However, further large-scale, long-term, randomized controlled trials are needed to confirm Baduanjin's superiority and explore its underlying mechanisms.

LDL is traditionally considered a cardiovascular risk factor, but its role in diabetes progression remains controversial [68]. A large retrospective study in Chinese adults found that increased LDL (≥ 2.16 mmol/L) may reduce prediabetes risk through mechanisms such as decreased pancreatic β-cell uptake of LDL particles [68]. Recent research suggests elevated low-density lipoprotein cholesterol does not necessarily increase cardiovascular risk [69]. Beebe et al. [69] found that after 16 weeks of Tai Chi, LDL concentrations did not significantly decrease. TCEs appeared to optimize LDL particle size, resulting in a slight increase in total LDL concentration. Our meta-analysis also did not observe significant changes in LDL concentrations, possibly due to the optimization of LDL particle size by TCEs rather than a direct reduction in LDL concentration. TCEs promote the generation and activity of lipoprotein lipase, reducing the likelihood of TG-LDL exchange, thereby increasing LDL particle size and transforming it into a healthier phenotype, which lowers cardiovascular risk [70, 71]. Thus, the metabolic role of LDL in individuals with prediabetes may have a dual nature, and focusing solely on its concentration changes may not fully assess metabolic health status.

This study found significant heterogeneity in some outcomes. To explore the sources of heterogeneity, we performed subgroup and meta-regression analyses. The results indicated that the primary sources of heterogeneity for HbA1c were intervention duration and TCE type; for 2hPG, it was session duration, TCE type, and sample size; for TG, it was related to TCE type; and for LDL, it was associated with TCE type and exercise frequency. Meta-regression revealed a significant association between sample size and 2hPG improvement, indicating that larger sample sizes reduce random error and variability, leading to more precise and generalizable results. Identifying sample size as a key source of heterogeneity underscores the importance of addressing study-scale differences in future analyses. Future research should prioritize adequately powered studies to enhance the accuracy and generalizability of findings. In addition to sample size, meta-regression included other covariates such as baseline BMI, age, publication year, and male proportion to evaluate their potential contributions to heterogeneity. However, the analysis did not identify significant associations between these factors and the outcomes assessed (e.g., HbA1c, HDL). The limited variability in baseline BMI and age across the included studies further supports the finding that these factors likely have minimal impact on the observed heterogeneity. Additionally, we conducted a sensitivity analysis, which showed that removing individual studies had minimal effects on overall effect sizes and 95% confidence intervals, with the direction of the impact remaining consistent, indicating that the conclusions of this meta-analysis are robust and reliable. Notably, sensitivity analysis for HDL indicated that Ma2022c [35] (intervention duration ≥ 12 months) was the primary source of heterogeneity for HDL outcomes. However, subgroup analysis did not show significant statistical differences between subgroups ($P = 0.526$). This result may be due to the small sample size in the ≥ 12-month group ($n = 126$), which led to insufficient statistical power. However, We observed a trend of greater HDL improvement with longer intervention durations, aligning with the findings of meta-analyses by Yu et al. [19] and Dong et al. [72], which demonstrated that extended TCE interventions were associated with significant improvements in glycemic and lipid control in individuals with prediabetes. These results suggest a potential dose-response relationship between intervention duration and HDL improvement, warranting confirmation through more extensive, well-powered studies. Although sensitivity analyses supported the overall robustness of the findings, caution is warranted when extrapolating these results to populations with differing baseline characteristics or intervention conditions.

Limitations

First, this study included only RCTs, excluding observational studies and gray literature, which may limit the generalizability of the findings. While this approach ensured methodological rigor and minimized bias from non-peer-reviewed sources, it may have introduced publication bias by omitting studies with null or negative results. Future research should balance methodological quality with the inclusion of gray literature to improve the breadth and representativeness of evidence.

Second, the quality of the included literature was generally assessed as a moderate risk of bias, with the overall evidence quality ranging from very low to moderate. Many RCTs did not report the implementation of allocation concealment and blinding procedures in detail, leading to uncertainty in bias risk assessment. This lack of reporting may increase selection bias in study design and implementation.

Finally, most of the studies were conducted in China. TCEs are deeply rooted in culture and supported by the community, potentially enhancing adherence and magnifying intervention effects in this cultural context. However, this cultural specificity may limit the transferability of the findings to other regions or populations. Nevertheless, TCEs show great potential for application in public health, especially in community-based diabetes care and prevention, due to their low cost, accessibility, safety, and high adherence [42]. Future research should focus on developing effective strategies, such as culturally adapted educational materials, improved access to certified trainers, and integrating culturally rooted programs into community health initiatives [60, 73]. These efforts would enable TCEs to adapt to diverse cultural and healthcare settings, ensuring their global applicability and maximizing their health benefits.

Clinical implications

In this meta-analysis, although the observed reduction in HbA1c (0.28%) did not reach the conventional clinical significance threshold for the management of type 2 diabetes (typically defined as a reduction of ≥ 0.5%), its potential significance for individuals with prediabetes should not be underestimated. The primary objective of interventions in prediabetes is to prevent or delay the progression to type 2 diabetes rather than to alleviate clinical symptoms immediately. Recent evidence-based studies on lifestyle interventions have demonstrated that even modest reductions in HbA1c are valuable for diabetes prevention. For instance, the 2021 update of the U.S. National Diabetes Prevention Program (DPP) has incorporated a reduction in HbA1c by 0.2% as one of the key indicators for assessing the success of lifestyle interventions [74]. This suggests that the HbA1c reduction of 0.28% observed in our study may have significant clinical relevance in lowering the risk of progression from prediabetes to type 2 diabetes.

Practical implications

According to the ADA exercise guidelines, it is recommended that individuals engage in at least 150 min of moderate-to-vigorous intensity aerobic exercise per week, distributed over at least three days. However, our study found that engaging in TCEs for at least three months for individuals with prediabetes, with each session lasting 30 to 50 min, two to three times per week (totaling 60–150 min), significantly improved glycemic. In contrast, achieving significant improvements in lipid profiles may require longer durations of TCEs (≥ 12 months) to attain optimal effects. Compared to the moderate-to-vigorous intensity exercises recommended by the guidelines, such as running or cycling, traditional exercises like Tai Chi and Baduanjin are relatively gentle regarding intensity and movement requirements. These forms of exercise are more suitable for individuals with lower physical capacity or limited time, thereby enhancing adherence. Additionally, the lower initial exercise volume provides greater feasibility for those who are inactive, laying the foundation for gradually increasing exercise intensity and duration over time. Notably, the longer the intervention period, the more pronounced the improvement in metabolic indicators with TCEs. Therefore, we recommend that TCEs be adopted as a lifelong lifestyle intervention for preventing and managing diabetes, aiming to achieve sustained and widespread health benefits.

Conclusions

This systematic review and meta-analysis found that TCEs significantly improve blood glucose and lipid levels in individuals with prediabetes. As a low-cost, accessible, and easily adherent intervention, TCEs have broad potential for application in diabetes prevention and management. Future studies should include high-quality RCTs from diverse cultural backgrounds to verify long-term effects and dose-response relationships, maximizing TCEs' impact on global health.

Abbreviations

ADA	American Diabetes Association
IDF	International Diabetes Federation
T2D	Type 2 Diabetes
EIM	Exercise is Medicine"
BMI	Body Mass Index
HbA1c	Glycated Hemoglobin
FBG	Fasting Blood Glucose
2hPG	2-hour Plasma Glucose
TC	Total Cholesterol
TG	Triglycerides
HDL	High-Density Lipoprotein Cholesterol
LDL	Low-Density Lipoprotein Cholesterol
MD	Mean Difference
SD	Standard Deviation
95% CI	95% Confidence Interval
SE	Standard Error
TCEs	Traditional Chinese Exercises
RCT	Randomized Controlled Trial

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13098-025-01592-0 .

Supplementary Material 1

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Author contributions

RX and WW participated in the conception or design, acquisition, analysis, or interpretation of the data, and drafting and revising the manuscript. LD and JX participated in the acquisition, analysis, or interpretation of the data. SJ participated in revising the manuscript and supervision. SF, LJ, and DY participated in the acquisition, analysis, or interpretation of the data. All authors have read and approved the final version of the manuscript and agree with the order of authorship.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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