

Review

Association of traditional Chinese exercises with glycemic responses in people with type 2 diabetes: A systematic review and meta-analysis of randomized controlled trials

Ge Song^a, Changcheng Chen^a, Juan Zhang^a, Lin Chang^a, Dong Zhu^b, Xueqiang Wang^{a,*}

^a Department of Sports Rehabilitation, Shanghai University of Sport, Shanghai 200438, China

^b School of Wushu, Shanghai University of Sport, Shanghai 200438, China

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Abstract

Background: There is increasing evidence showing the health benefits of various forms of traditional Chinese exercises (TCEs) on the glycemic profile in people with type 2 diabetes. However, relatively little is known about the combined clinical effectiveness of these traditional exercises. This study was designed to perform a systematic review and meta-analysis of the overall effect of 3 common TCEs (Tai Ji Quan, Qigong, Ba Duan Jin) on glycemic control in adults with type 2 diabetes.

Methods: We conducted an extensive database search in Cochrane Library, EMBASE, PubMed, Web of Science, EBSCO, and China National Knowledge Infrastructure on randomized controlled trials published between April 1967 and September 2017 that compared any of the 3 TCEs with a control or comparison group on glycemic control. Data extraction was performed by 2 independent reviewers. Study quality was evaluated using the *Cochrane Handbook for Systematic Reviews of Interventions*, which assessed the risk of bias, including sequence generation, allocation concealment, blinding, completeness of outcome data, and selective outcome reporting. The resulting quality of the reviewed studies was characterized in 3 grades representing the level of bias: low, unclear, and high. All analyses were performed using random effects models and heterogeneity was quantified. We *a priori* specified changes in biomarkers of hemoglobin A1c (in percentage) and fasting blood glucose (mmol/L) as the main outcomes and triglycerides, total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein-cholesterol, 2-h plasma glucose, and fasting plasma glucose as secondary outcomes.

Results: A total of 39 randomized, controlled trials (Tai Ji Quan = 11; Qigong = 6; Ba Duan Jin = 22) with 2917 type 2 diabetic patients (aged 41–80 years) were identified. Compared with a control or comparison group, pooled meta-analyses of TCEs showed a significant decrease in hemoglobin A1c (mean difference (MD) = −0.67%; 95% confidence interval (CI): −0.86% to −0.48%; $p < 0.00001$) and fasting blood glucose (MD = −0.66 mmol/L; 95%CI: −0.95 to −0.37 mmol/L; $p < 0.0001$). The observed effect was more pronounced for interventions that were medium range in duration (i.e., >3–<12 months). TCE interventions also showed improvements in the secondary outcome measures. A high risk of bias was observed in the areas of blinding (i.e., study participants and personnel, and outcome assessment).

Conclusion: Among patients with type 2 diabetes, TCEs were associated with significantly lower hemoglobin A1c and fasting blood glucose. Further studies to better understand the dose and duration of exposure to TCEs are warranted.

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Keywords: Blood glucose; Hypoglycemia; Insulin sensitivity; Physical activity

1. Introduction

Diabetes mellitus, especially type 2 diabetes, constitutes a global public health problem.¹ Most recent estimates show that, globally, approximately 415 million people live with diabetes, of

which type 2 diabetes accounts for 90% of the diabetes population.² As the prevalence of diabetes continues to increase worldwide, particularly among middle- and low-income countries,^{3,4} the World Health Organization projects that the disease will become the seventh leading cause of death by 2030.¹ If not appropriately treated or managed, diabetes mellitus will have profound short- and long-term medical complications and, concomitantly, pose a significant economic burden to health care systems.²

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* Corresponding author.

E-mail address: qiang897@163.com (X. Wang).

Mounting evidence indicates that exercise produces significant physiological and health benefits^{5–10} and prevents or delays the development of type 2 diabetes.^{11,12} Therefore, exercise is recommended for all individuals with diabetes as a part of the management of glycemic control and overall health.¹³ In the past 2 decades, however, there has also been an increasing interest in discovering the health benefits of alternative, traditional Chinese exercises (TCEs) such as Tai Ji Quan, Qigong, and Ba Duan Jin.^{14–16} Emerging randomized controlled trials (RCTs) and meta-analyses have reported beneficial effects of TCEs on glycemic profile in people with type 2 diabetes.^{17–21}

Despite the potential benefits of TCEs for diabetic care, various design and methodologic weaknesses have consistently been identified across studies. The lack of scientific rigor observed in many RCTs has decreased the robustness of the findings, thus limiting broad generalizability. In addition, systematic reviews have often focused on single exercises, which may not reflect the collective health benefits of TCEs. To address these shortcomings, we extended previous individual reviews^{17–21} to include recently published trials by conducting a systematic review and meta-analysis of the combined effects of 3 major and commonly studied TCEs (Tai Ji Quan, Qigong, and Ba Duan Jin) on the clinical biomarkers of glycemic control for adults with type 2 diabetes.

2. Methods

2.1. Protocol and registration

This study was conducted in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines.²² The protocol was registered with the PROSPERO database (No. CRD42013006474).

2.2. Search strategy

Data sources used in this systematic review and meta-analysis included Cochrane Library, EMBASE, PubMed, Web of Science, EBSCO, and China National Knowledge Infrastructure. The electronic search used a mix of MeSH and free text terms to identify peer-reviewed articles on TCE-based RCTs that involved adults with type 2 diabetes. Accordingly, we used the search terms relevant to “randomized controlled trial”, “type 2 diabetes”, “traditional Chinese exercises”, “glycemic control”, and “hyperglycemia”. A detailed description of search strategies is presented in the Appendix. The search was performed by 2 independent reviewers (CC, DZ) with restrictions imposed on the year of publication (from the origin of the database to September 2017) and language (English or Chinese), the studies that involved human participants, and published articles. No search was conducted on abstracts presented at international conferences.

2.3. Inclusion and exclusion criteria

We considered *a priori* RCTs that examined the efficacy of any of the 3 *a priori* specified exercises (Tai Ji Quan, Qigong, or Ba Duan Jin) versus a control or other form of comparison (e.g., sham exercise, aerobic exercise, or routine treatment) on

type 2 diabetes. The study population had to involve adults (≥ 18 years old) with type 2 diabetes, medically defined by a diagnosis of fasting blood glucose level of ≥ 7.0 mmol/L (≥ 126 mg/dL), a 2-h plasma glucose of ≥ 11.1 mmol/L (200 mg/dL), or a hemoglobin A1c (HbA1c) of $\geq 6.5\%$.²³ The study outcomes had to include biomarkers for diabetic risk factors, including HbA1c, fasting blood glucose, triglyceride, total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, 2-h plasma glucose, homeostasis model assessment, and fasting plasma glucose.

2.4. Data extraction and synthesis

Data extraction was performed independently by 2 reviewers (JZ, LC) in prespecified forms. The extraction included information on study population; total number of participants; intervention design; characterizes of intervention, including type, frequency, and duration; clinical outcome measures; and the results of the trial. In addition, descriptive statistics such as the number of study participants, trial duration, and mean and standard deviation of outcome measures at each assessment point (baseline, after the intervention) for the intervention and comparison groups were extracted. Information on the duration of interventions (≤ 3 , >3 – <12 , and ≥ 12 months) was recorded. We also checked the research articles that met the eligibility criteria for duplicate reporting of the same data. Any conflicts or ambiguities in the reported methods or results occurring during the data extraction process were discussed with a third reviewer (XW) and resolved by consensus.

2.5. Outcomes

The *a priori* primary outcomes of the study were HbA1c, recorded as percentage change, and fasting blood glucose, measured in the unit of mmol/L. Secondary outcomes included other biomarkers of triglycerides, total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, 2-h plasma glucose, and fasting plasma glucose, all measured in millimoles per liter. In addition, adverse events in the included studies, if any, were documented.

2.6. Risk of bias appraisal for individual studies

We used the Cochrane Handbook for Systematic Reviews of Interventions²⁴ tool to conduct an overall assessment of risk of bias in systematic review (JZ, LC). For each RCT, we assessed sequence generation; allocation concealment; blinding of participants, staff, and outcome assessors; completeness of outcome data; and selective outcome reporting. The resulting evaluation was classified into 3 grades: low, unclear, and high risk of bias. Any discrepancies encountered during evaluation were discussed by inviting a third reviewer (XW) and resolved by consensus.

2.7. Data analysis

If there were intent-to-treat data in our eligible studies, we preferred to use the intent-to-treat data. In each study, the difference in the study outcomes between the means of the exercise and comparison (control) groups at the end of the intervention was first

calculated. We then computed the mean difference (MD) using the pooled data across the included studies via a random effect meta-analysis model. As an *a priori* analysis, we also analyzed the resulting data across 3 intervention durations, defined as short (≤ 3 months), medium (>3 – <12 months), and long term (≥ 12 months). We presented the point estimates and their corresponding 95% confidence intervals (CIs). Tests of heterogeneity were performed using the Q statistic (with $p < 0.10$ indicating statistically significant heterogeneity). For all other analyses, an α level of 0.05 was set *a priori* for statistical significance. We examined publication bias using forest plots and Egger's regression asymmetry test. To verify the reliability of our meta-analysis results, we conducted a sensitivity analysis by removing each study one by one to assess the consistency and quality of results. The meta-analyses were conducted using the Review Manager software (Version 5.2; The Nordic Cochrane Centre, Copenhagen, Denmark).

3. Results

3.1. Search results

The flow of records through the review is summarized in Fig. 1. Our electronic searches resulted in 1117 potentially eligible reports or articles. We excluded 1005 of these based on the title, abstract, or repeated records. Of the 112 remaining articles, an additional 73 were excluded. The most common reasons for exclusion were a non-RCT design, unrelated outcomes, or non-type 2 diabetes. Eventually, 39 RCTs were deemed eligible for inclusion and synthesized for effectiveness.

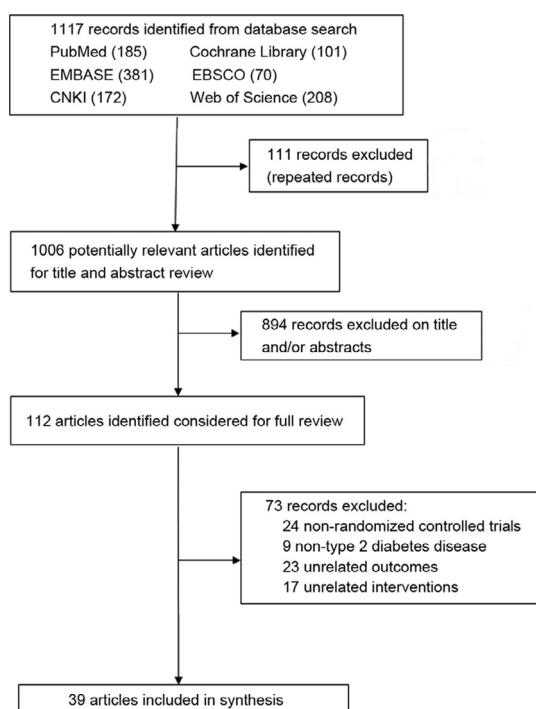


Fig. 1. Flow chart of study selection. CNKI=China National Knowledge Infrastructure.

3.2. Study characteristics

All eligible studies were published between 2004 and 2017, and the studies varied in size, duration, and intervention type. A total of 2917 individuals participated in the 39 eligible trials that were subsequently meta-analyzed. Trial sample sizes ranged from 20 to 216 participants (median, 60; total, 2917). The duration of follow-up ranged from 1 to 12 months (median 4 months). With respect to TCE type, 11 involved a Tai Ji Quan intervention, 6 involved Qigong, and 22 involved Ba Duan Jin. The mean age of participants in the 39 studies (when this information was available) was 58.9 years and 48.8% of participants were women. Of the 39 eligible studies, 38 reported on HbA1c or fasting blood glucose levels (97.4%) and 25 had both main and secondary outcomes (64.1%). Results from 24 RCTs were analyzed using intent-to-treat data. The methodologic characteristics of the included studies are summarized in Table 1.

3.3. Risk of bias

The risk of bias assessment of all included studies is shown in Fig. 2. All of the included studies described the process of random sequence generation. More than one-half of the studies ($n = 22$; 56.4%) were classified as having an unclear risk in the domains of allocation concealment. A high risk of bias was detected in the domain of blinding; none of the studies blinded participants and investigators and only 6 (15.4%) of them were shown to blind their outcome assessment. A low risk of incomplete outcome data bias was observed in all of the studies ($n = 39$; 100%). With respect to selective outcome reporting bias, 36 (92.3%) studies were graded as low risk and the remaining were graded as unclear risk ($n = 3$; 7.7%).

3.4. Effects of TCEs on primary outcomes

The results showed that, overall, compared with a control or comparison group, TCEs significantly lowered the percentage of HbA1c (MD = -0.67% ; 95%CI: -0.86% to -0.48% ; $p < 0.00001$) and fasting blood glucose (MD = -0.66 mmol/L; 95%CI: -0.95 to -0.37 mmol/L; $p < 0.0001$; Table 2; Figs. 3 and 4). The effect on HbA1c was most pronounced in both short-term (MD = -0.51% ; 95%CI: -0.74% to -0.28% ; $p < 0.0001$) and medium-term durations of study (MD = -0.78% ; 95%CI: -1.06% to -0.50% ; $p < 0.00001$), with a marginal effect in the studies with a long-term duration of study (MD = -1.00% ; 95%CI: -2.04% to 0.03% ; $p = 0.06$). In contrast, TCEs showed a significant effect on fasting blood glucose in studies conducted with medium-term durations (MD = -0.87 mmol/L; 95%CI: -1.38 to -0.35 mmol/L; $p = 0.001$) and long-term durations (MD = -0.55 mmol/L; 95%CI: -0.70 to -0.40 mmol/L; $p < 0.00001$), but not in the short-term duration studies (MD = -0.42 mmol/L; 95%CI: -0.99 to 0.16 mmol/L; $p = 0.16$). There is, in general, significant heterogeneity shown in these point estimates (Table 2).

3.5. Effects of TCEs on secondary outcomes

As shown in Table 2, TCEs were shown to have a significant effect on all secondary outcomes. With respect to

Table 1
Characteristics of study design, intervention, and participants.

Author, year	Sample size, participant characteristic ^a	Intervention	Exercise frequency	Outcome	Study duration
Yu, 2004 ²⁵	40 subjects, mean age: G1 = 50.0 ± 5.8 G2 = 49.0 ± 5.6	G1: TJQ G2: routine treatment	Once per day	FBG, HbA1c	12 weeks
Wang et al., 2007 ²⁶	79 subjects, mean age: G1 = 57.8 ± 7.5 G2 = 56.5 ± 6.9	G1: BDJ + QG G2: routine treatment	Once per day	TG, TC, HDL-C, HbA1c	6 months
Lam et al., 2008 ²⁷	53 subjects, mean age: G1 = 63.2 ± 8.6 G2 = 60.7 ± 12.2	G1: TJQ G2: routine treatment	Two 1-h classes per week for 3 months, then once per week for 3 months	TG, TC, HbA1c	6 months
Pan et al., 2008 ²⁸	48 subjects, mean age: G1 = 47.0 ± 7.0 G2 = 45.0 ± 9.0	G1: BDJ G2: routine treatment	Once per day, 5 days per week	TC, HDL-C, FBG, HbA1c	24 weeks
Tsang et al., 2008 ²⁹	38 subjects, mean age: G = 65.0 ± 7.8	G1: TJQ G2: sham exercise	Twice per week	HbA1c	16 weeks
Lin et al., 2009 ³⁰	94 subjects, mean age: G1 = 59.3 ± 5.2 G2 = 59.8 ± 6.9 G3 = 59.1 ± 6.3 G4 = 55.3 ± 8.6	G1: BDJ G2: BDJ + relaxation G3: relaxation G4: routine treatment	Once per day	FBG, HbA1c	2 months, 4 months
Lin et al., 2009 ³¹	94 subjects, mean age: G1 = 59.3 ± 5.2 G2 = 59.8 ± 6.9 G3 = 59.1 ± 6.3 G4 = 55.3 ± 8.6	G1: BDJ G2: BDJ + relaxation G3: relaxation G4: routine treatment	Once per day	FBG, HbA1c	4 months
Wang et al., 2009 ³²	54 subjects, mean age: G1 = 49.2 ± 11.1 G2 = 48.8 ± 10.5	G1: TJQ G2: social dancing exercise	5–7 times per week	TG, LDL-C, HDL-C, FBG, HbA1c	6 months
Chen et al., 2010 ³³	104 subjects, mean age: G1 = 59.1 ± 6.2 G2 = 57.4 ± 5.8	G1: TJQ G2: the Hi-Low aerobic exercises	3 times per week	TG, TC, HDL-C, FBG, HbA1c	12 weeks
Huang et al., 2011 ³⁴	60 subjects, mean age: G1 = 57.8 ± 7.5 G2 = 56.5 ± 6.9	G1: BDJ + QG G2: routine treatment	Once per day	TG, TC, LDL-C, HDL-C, HbA1c, FPG	6 months
Liu et al., 2011 ³⁵	41 subjects, age: G = 41–71	G1: QG G2: routine treatment	3 times per week	TG, HDL-C, FBG, HbA1c, 2-h PG	12 weeks
Zhou et al., 2011 ³⁶	122 subjects, mean age: G1 = 67.4 ± 9.2 G2 = 68.1 ± 10.6	G1: BDJ G2: aerobic exercises	G1: Twice per week G2: 3–5 times per week	TG, LDL-C, HDL-C, HbA1c	3 months
Ahn et al., 2012 ³⁷	39 subjects, mean age: G1 = 66.0 ± 6.4 G2 = 62.7 ± 7.5	G1: QG G2: routine treatment	1-h session twice per week	FBG, HbA1c	12 weeks
Guan et al., 2012 ³⁸	80 subjects, mean age: G1 = 59.2 ± 8.8 G2 = 58.7 ± 8.3	G1: BDJ G2: routine treatment	Once per day	TG, FBG, HbA1c, 2-h PG	4 months
Ji et al., 2012 ³⁹	62 subjects, mean age: G1 = 60.3 ± 7.2 G2 = 60.2 ± 7.1	G1: QG + diabetes education + routine treatment G2: diabetes education + routine treatment	Once per day	HbA1c, 2-h PG, FPG	2 months
Liu et al., 2012 ⁴⁰	69 subjects, mean age: G1 = 62.6 ± 5.9 G2 = 65.6 ± 8.3	G1: BDJ + community health education + routine treatment G2: community health education + routine treatment	Once per day, 3–5 days per week	HbA1c	6 weeks, 12 weeks
Cheng et al., 2013 ⁴¹	40 subjects, mean age: G1 = 65.5 ± 6.2 G2 = 61.9 ± 7.0	G1: QG G2: routine treatment	1 h per day, 2–3 days per week	TG, TC, LDL-C, HDL-C, FBG, HbA1c, 2-h PG	12 months
Li et al., 2013 ⁴²	216 subjects, mean age: G1 = 50.4 ± 9.6 G2 = 51.6 ± 7.8 G3 = 54.2 ± 9.4 G4 = 52.6 ± 8.3	G1: BDJ G2: general aerobic exercise G3: TJQ G4: routine treatment	Once per day	TC, HDL-C, HbA1c, FPG	3 months, 9 months
Lin and Wei, 2013 ⁴³	38 subjects, mean age: G1 = 64.5 ± 11.5 G2 = 60.8 ± 12.2	G1: BDJ G2: routine treatment	Once per day	TG, TC, LDL-C, HDL-C, HbA1c, FPG	6 months

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Table 1 (Continued)

Author, year	Sample size, participant characteristic ^a	Intervention	Exercise frequency	Outcome	Study duration
Li and Wang, 2014 ⁴⁴	40 subjects, mean age: G1 = 53.6 ± 8.7 G2 = 51.4 ± 9.2	G1: BDJ G2: Routine treatment	Once per day	HbA1c, FPG	4 weeks
Liu et al., 2014 ⁴⁵	40 subjects, mean age: G1 = 57.0 ± 7.0 G2 = 55.0 ± 9.0	G1: BDJ G2: routine treatment	Once per day, 5 days per week	HbA1c	6 months
Lu et al., 2014 ⁴⁶	120 subjects, mean age: G1 = 52.5 ± 1.7 G2 = 48.0 ± 2.0	G1: QG G2: routine treatment	Once per day	HbA1c	12 months
Meng, 2014 ⁴⁷	200 subjects, mean age: G = 68.4 ± 3.2	G1: TJQ G2: routine treatment	Once per day	TG, TC, LDL-C, HDL-C, FBG, HbA1c	3 months
Zhou, 2014 ⁴⁸	25 subjects, age: G1 = 51–72 G2 = 58–80	G1: BDJ + QG G2: routine treatment	Once per day	FBG, HbA1c	3 months
Cao et al., 2015 ⁴⁹	60 subjects, mean age: G1 = 58.9 ± 9.6 G2 = 62.3 ± 9.9	G1: BDJ G2: routine treatment	Twice per day	HbA1c	12 weeks
Cao et al., 2015 ⁵⁰	60 subjects, mean age: G1 = 58.4 ± 9.1 G2 = 60.8 ± 9.5	G1: BDJ G2: routine treatment	Twice per day	HbA1c, FPG	8 weeks
Li et al., 2015 ⁵¹	100 subjects, mean age: G1 = 62.9 ± 2.4 G2 = 63.2 ± 2.8	G1: TJQ G2: aerobic exercise	Once per day	TG, TC, LDL-C, HDL-C, HbA1c, FPG	6 months
Sun, 2015 ⁵²	65 subjects, mean age: G = 46.1 ± 11.8	G1: BDJ + relaxation G2: routine treatment	Twice per week	HbA1c, 2-h PG, FPG	6 months
Wang and Zhang, 2015 ⁵³	60 subjects, mean age: G1 = 61.7 ± 6.9 G2 = 61.3 ± 8.4	G1: BDJ G2: routine treatment	5 times per week	TG, TC, LDL-C, HDL-C, FBG, HbA1c	6 weeks
Wu and Wei, 2015 ⁵⁴	60 subjects, mean age: G1 = 63.9 ± 7.6 G2 = 64.8 ± 5.8 G3 = 65.3 ± 6.0	G1: BDJ G2: walking G3: routine treatment	G1: 3 times per day, 5–7 days per week; G2: twice per day, 5–7 days per week; G3: daily routine	HbA1c, FPG	3 months
Zhang et al., 2015 ⁵⁵	108 subjects, mean age: G1 = 57.0 ± 2.4 G2 = 55.4 ± 1.7 G3 = 58.2 ± 1.0	G1: BDJ G2: aerobic exercise G3: routine treatment	Once per day	HbA1c, FPG	100 days
Hou, 2016 ⁵⁶	62 subjects, mean age: G1 = 58.8 ± 6.7 G2 = 58.9 ± 6.4	G1: BDJ G2: routine treatment	5 days per week	TG, TC, HDL-C, HbA1c	6 months
Wang et al., 2016 ⁵⁷	94 subjects, mean age: G1 = 63.3 ± 7.0 G2 = 64.4 ± 6.3	G1: TJQ + BDJ G2: routine treatment	Once per day	TG, TC, LDL-C, HDL-C, HbA1c	6 months
Yin et al., 2016 ⁵⁸	88 subjects, mean age: G1 = 56.4 ± 5.6 G2 = 55.4 ± 9.1	G1: BDJ G2: routine treatment	Once per day	TG, LDL-C, HDL-C, FBG, HbA1c	6 months
Gao, 2017 ⁵⁹	120 subjects, mean age: G1 = 61.2 ± 5.9 G2 = 62.3 ± 6.6	G1: QG G2: routine treatment	5 days per week	HbA1c, FPG	3 months
Orr et al., 2006 ⁶⁰	35 subjects, mean age: G1 = 65.9 ± 7.4 G2 = 64.9 ± 8.1	G1: TJQ G2: sham exercise	Twice per week	FBG	4 months
Xiao et al., 2011 ⁶¹	48 subjects, mean age: G = 55.0 ± 4.1	G1: TJQ G2: puerarin G3: TJQ + puerarin G4: routine treatment	Once per day	FBG	6 months
Peng et al., 2015 ⁶²	141 subjects	G1: BDJ G2: routine treatment	Once per day	FBG	6 months
Zhang and Fu, 2008 ⁶³	20 subjects, mean age: G = 57.4 ± 6.2	G1: TJQ G2: routine treatment	1 h per day, 5 days per week	TG, TC, LDL-C, HDL-C, FPG	14 weeks

Notes: ^aThe unit of age is year. Data presented as mean ± SD for the “mean age”.

Abbreviations: 2-h PG = 2-h plasma glucose; BDJ = Ba Duan Jin; FBG = fasting blood glucose; FPG = fasting plasma glucose; G = group; HbA1c = hemoglobin A1c; HDL-C = high-density lipoprotein cholesterol; LDL-C = low-density lipoprotein cholesterol; QG = Qigong; TC = total cholesterol; TG = triglyceride; TJQ = Tai Ji Quan.

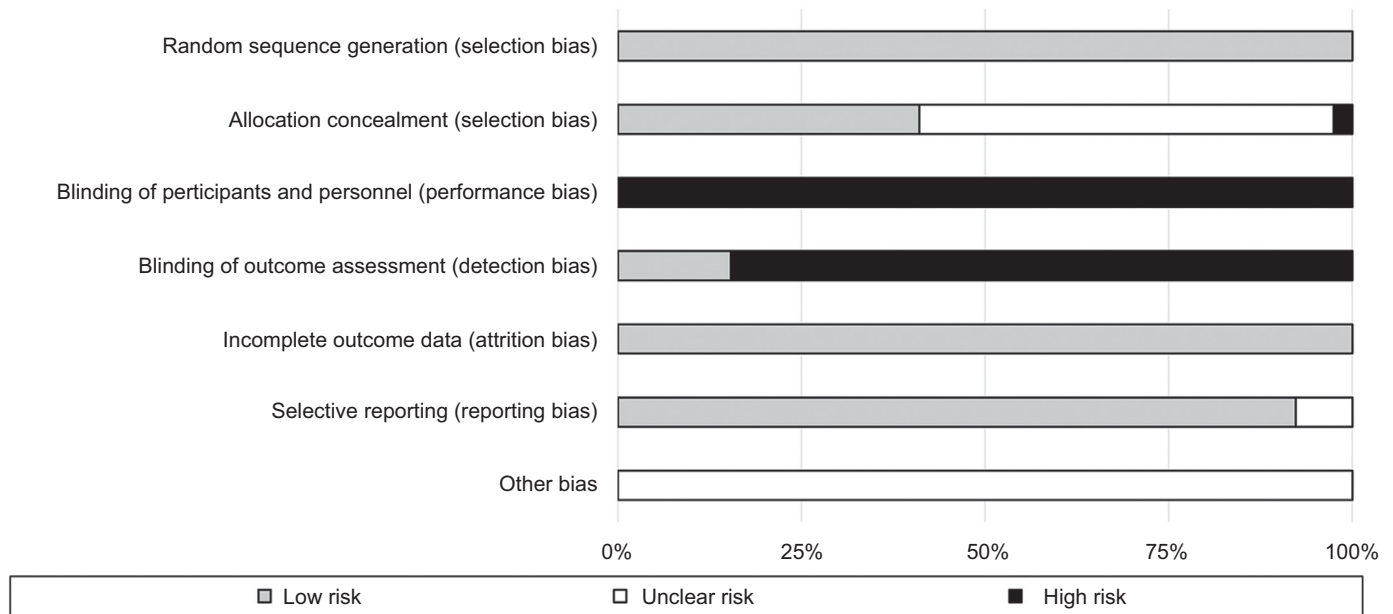


Fig. 2. Risk of bias assessment.

responses to different intervention lengths, only 2 nonsignificant results were observed in the outcomes of low-density lipoprotein cholesterol (MD = -0.14; 95%CI: -0.41 to 0.13;

$p = 0.31$) for the studies that had a medium-term duration and high-density lipoprotein cholesterol (MD = 0.06; 95%CI: -0.02 to 0.14; $p = 0.15$) for those with a short-term duration.

Table 2
Summary of the meta-analysis results by study length.

Outcome	Number of RCTs	No. of participants	Effect estimate (95%CI)	Heterogeneity	<i>p</i>
Main outcomes					
HbA1c (%)	35 ²⁵⁻⁵⁹	2940	-0.67 (-0.86 to -0.48)	<0.00001	<0.00001
Short term	17 ^{25,30,33,35-37,39,40,42,44,47-50,53,54,59}	1402	-0.51 (-0.74 to -0.28)	<0.00001	<0.0001
Medium term	18 ^{26-32,34,38,42,43,45,51,52,55-58}	1378	-0.78 (-1.06 to -0.50)	<0.00001	<0.00001
Long term	2 ^{41,46}	160	-1.00 (-2.04 to 0.03)	0.02	0.06
FBG (mmol/L)	18 ^{25,28,30-33,35,37,38,41,46-48,53,58,60-62}	1433	-0.66 (-0.95 to -0.37)	<0.00001	<0.0001
Short term	8 ^{25,30,33,35,37,47,48,53}	593	-0.42 (-0.99 to 0.16)	<0.0001	0.16
Medium term	9 ^{28,30-32,38,58,60,61,62}	680	-0.87 (-1.38 to -0.35)	0.001	0.001
Long term	2 ^{41,46}	160	-0.55 (-0.70 to -0.40)	0.70	<0.00001
Secondary outcomes					
TG (mmol/L)	17 ^{26,27,32-36,38,41,43,47,51,53,56-58,63}	1283	-0.49 (-0.71 to -0.26)	<0.00001	<0.0001
Short term	5 ^{33,35,36,47,53}	517	-0.49 (-0.86 to -0.12)	0.005	0.01
Medium term	11 ^{26,27,32,34,38,43,51,56-58,63}	726	-0.47 (-0.77 to -0.16)	<0.00001	0.003
TC (mmol/L)	14 ^{26-28,33,34,41-43,47,51,53,56,57,63}	1303	-0.41 (-0.57 to -0.25)	0.006	<0.00001
Short term	4 ^{33,42,47,53}	570	-0.36 (-0.65 to -0.07)	0.05	0.01
Medium term	10 ^{26-28,34,42,43,51,56,57,63}	693	-0.47 (-0.66 to -0.28)	0.04	<0.00001
LDL-C (mmol/L)	11 ^{32,34,36,41,43,47,51,53,57,58,63}	876	-0.23 (-0.41 to -0.06)	0.001	0.008
Short term	3 ^{36,47,53}	382	-0.36 (-0.51 to -0.20)	0.46	<0.00001
Medium term	7 ^{32,34,43,51,57,58,63}	454	-0.14 (-0.41 to 0.13)	0.0002	0.31
HDL-C (mmol/L)	17 ^{26,28,32-36,41-43,47,51,53,56-58,63}	1632	0.14 (0.07 to 0.21)	<0.00001	0.0002
Short term	6 ^{33,35,36,42,47,53}	733	0.06 (-0.02 to 0.14)	0.17	0.15
Medium term	11 ^{26,28,32,34,42,43,51,56-58,63}	859	0.13 (0.05 to 0.21)	0.0003	0.002
2-h PG (mmol/L)	5 ^{35,38,39,41,52}	288	-2.14 (-2.79 to -1.49)	0.74	<0.00001
Short term	2 ^{35,39}	103	-2.45 (-3.66 to -1.25)	0.43	<0.0001
Medium term	2 ^{38,52}	145	-2.21 (-3.07 to -1.34)	0.99	<0.00001
FPG (mmol/L)	12 ^{34,39,42-44,50-52,54,55,59,63}	1142	-0.85 (-1.31 to -0.39)	<0.0001	0.0003
Short term	6 ^{39,42,44,50,54,59}	558	-0.71 (-1.15 to -0.26)	0.06	0.002
Medium term	7 ^{34,42,43,51,52,55,63}	584	-1.08 (-2.01 to -0.14)	<0.0001	0.02

Abbreviations: 2-h PG=2-h plasma glucose; CI=confidence interval; FBG=fasting blood glucose; FPG=fasting plasma glucose; HbA1c=hemoglobin A1c; HDL-C=high-density lipoprotein cholesterol; LDL-C=low-density lipoprotein cholesterol; RCT=randomized controlled trial; TC=total cholesterol; TG=triglycerides.

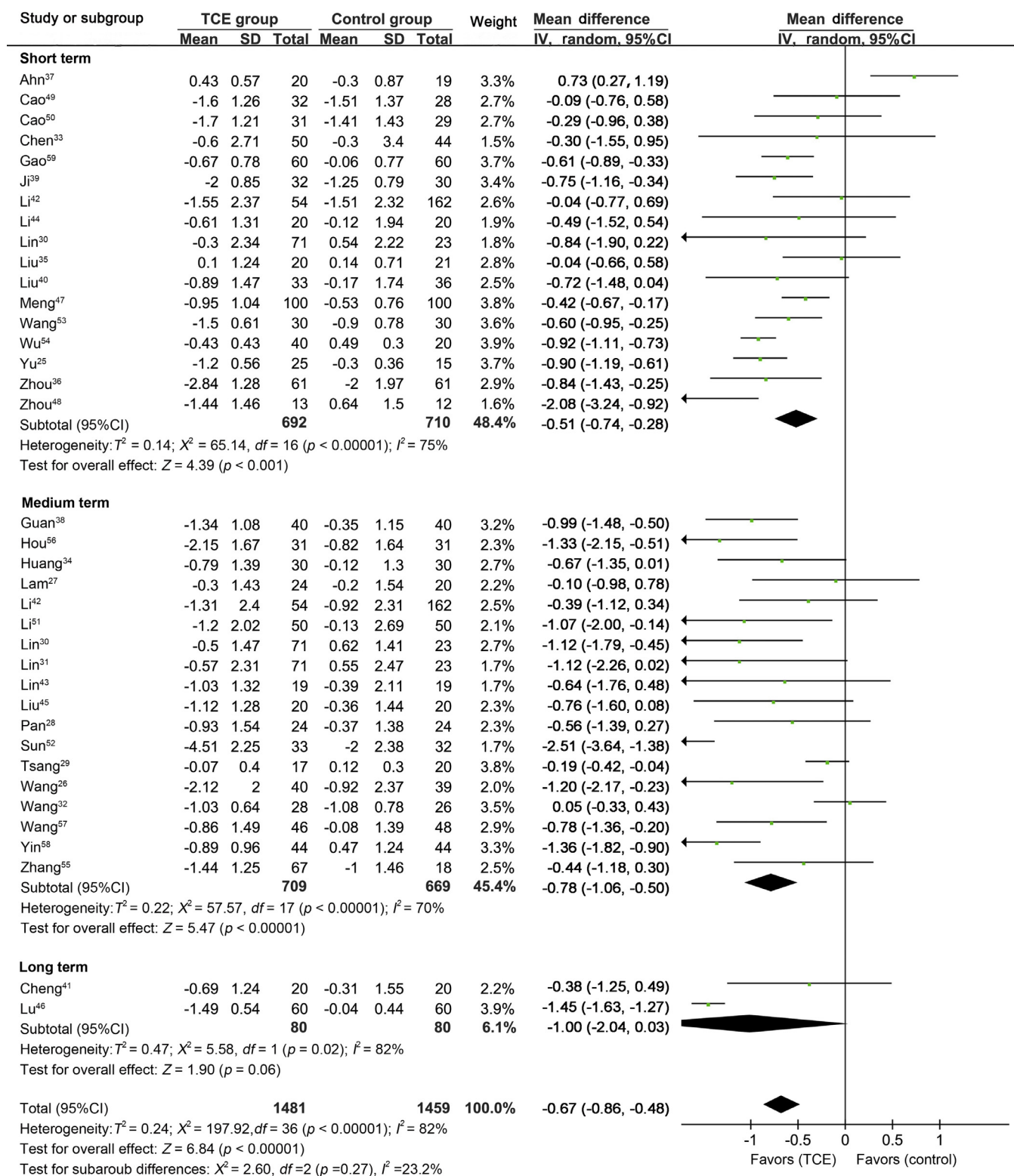


Fig. 3. Forest plot on hemoglobin A1c outcome in randomized, controlled trials with short-, medium-, and long-term durations. Forest plot showing the mean difference in change in hemoglobin A1c between TCEs and control/comparison groups across the studies that were conducted in short-, medium-, and long-term durations. CI = confidence interval; IV = inverse variance; SD = standard deviation; TCE = traditional Chinese exercise.

3.6. Adverse events

None of the studied reported adverse events. Therefore, this information could not be retrieved from the RCTs analyzed.

3.7. Sensitivity analysis

By removing single studies, the sensitivity analyses showed no noticeable changes in the statistical significance of all primary or secondary outcomes.

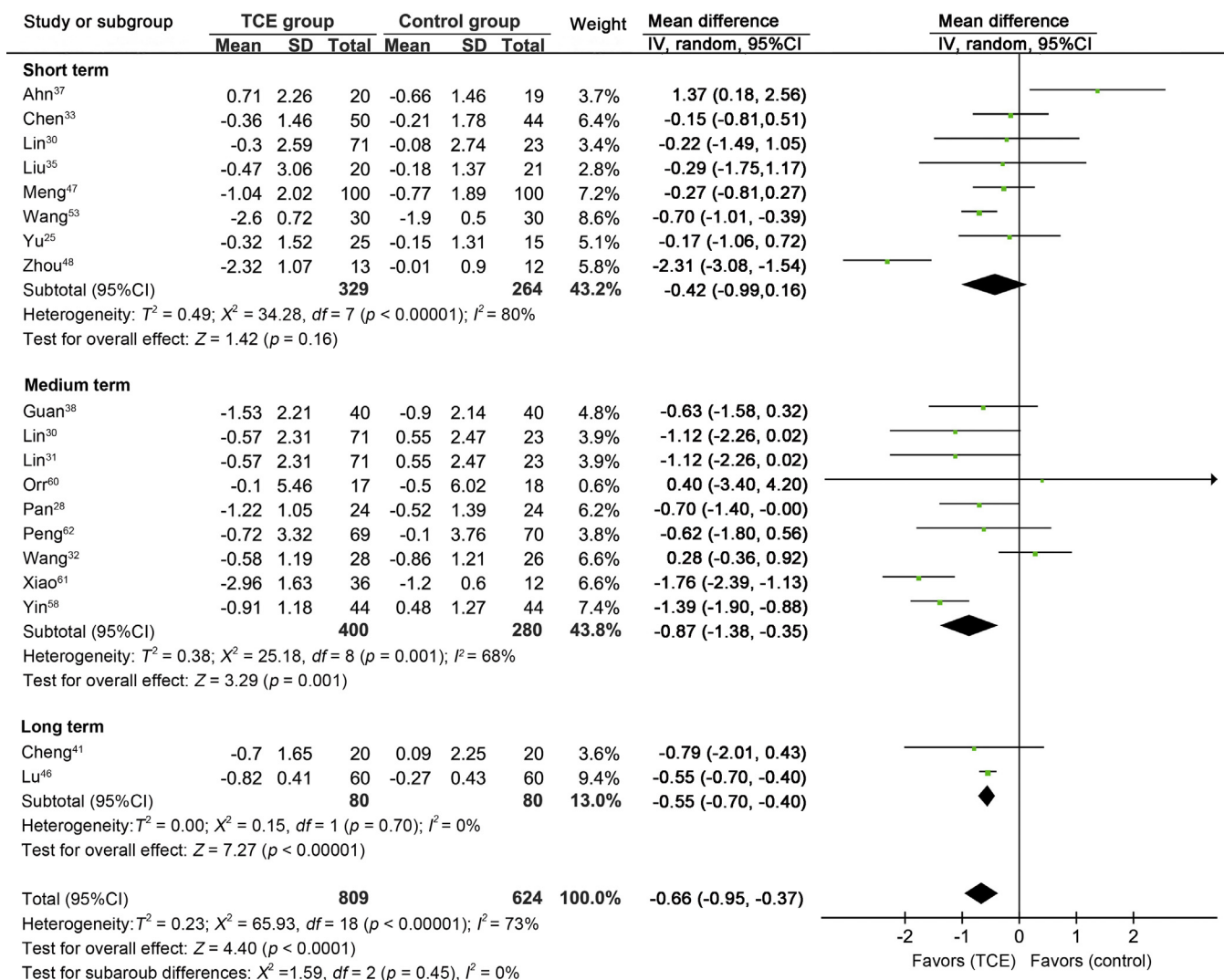


Fig. 4. Forest plot on fasting blood glucose outcome in randomized, controlled trials with short-, medium-, and long-term durations. Forest plot showing the mean difference in change in fasting blood glucose between TCEs and control/comparison groups across the studies that were conducted in short-, medium-, and long-term durations. CI = confidence interval; IV = inverse variance; SD = standard deviation; TCE = traditional Chinese exercise.

3.8. Publication bias

As shown from the Egger's asymmetry tests, there was little indication of publication bias on the primary outcomes ($p = 0.147$ for HbA1c; $p = 0.418$ for fasting blood glucose, respectively). Among secondary outcomes, the Egger's test showed publication bias only on high-density lipoprotein cholesterol ($p = 0.041$).

4. Discussion

Our study is the first to conduct a systematic review and meta-analysis of pooled effects among the 3 most common TCEs on clinical biomarkers of diabetes control. In our meta-analysis of the pooled results from 39 RCTs that included 2917 individuals with type 2 diabetes, we found that, on average, compared with a control/comparison group, combined TCE interventions reduced HbA1c (0.67% lower) and fasting blood glucose (0.66 mmol/L lower). In addition, we found good evidence that TCE interventions lowered the level of HbA1c with

interventions that were implemented in both short-term (i.e., ≤ 3 months) and medium-term (i.e., >3 – <12 months) durations and fasting blood glucose on medium-term (i.e., >3 – <12 months) and long-term (≥ 12 months) durations. TCEs also had a positive effect in improving secondary study biomarkers, including triglycerides, total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, and 2-h plasma glucose. In general, there was high heterogeneity observed in these estimates across interventions of different lengths.

Results from our meta-analyses are generally congruent with previous systematic reviews and meta-analysis reports of single TCEs on glycemic responses in people with type 2 diabetes.^{17–21} For example, positive impacts of Ba Duan Jin plus conventional therapy and Qigong interventions on HbA1c, fasting blood glucose, and other biomarkers have been reported.^{18,19} The impact of Tai Ji Quan, however, was less consistent, with some positive results occurring for HbA1c and fasting blood glucose when comparing Tai Ji Quan with either a control or other experimental conditions.^{17,21} By

pooling available TCE intervention data published between 2004 and 2017, we were able to show a consistent positive effect of combined TCE interventions on glycemic biomarkers that are highly relevant to diabetes control and management.

Our analyses by studies of different intervention durations show that TCE interventions lasting >3 – <12 months generally produced consistent results on reductions in both HbA1c and fasting blood glucose. These results could possibly be explained by the slow and meditative nature of exercises inherent in many of the TCE modalities being evaluated (e.g., Tai Ji Quan, Qigong, and Ba Duan Jin).^{14–16} We found no long-term (i.e., ≥ 12 months) practice effect of TCEs on HbA1c. Although short-term interventions (i.e., ≤ 3 months) were shown to decrease the level of HbA1c, they did not bring about a change in fasting blood glucose, suggesting that a longer training period may be necessary to elicit a clinical reduction. Although the exact mechanism for the inconsistent findings remains unknown, factors such as low intervention dose or intensity, nonblinding in outcome assessment, or poor quality in fidelity control may have played a role. Future studies designed with high scientific rigor are needed to better understand the impact of short- and long-term TCE training on glycemic control.

4.1. Study limitations

The study has some notable limitations. Among the RCTs included, there was great heterogeneity with respect to intervention intensity, duration, and frequency that may have contributed to unwanted heterogeneity and, consequently, may have further influenced the study outcomes. Even with our categorization of intervention durations (i.e., short, medium, and long term), the relatively small number of studies included in each category did not allow us to effectively account for the heterogeneity underlying the different studies in our random effect models. Therefore, the extent to which exercise dose or duration impacts exercise-induced improvement of glycemic control remains to be elucidated. Moreover, as previously reported,^{17,20} the methodologic quality of the RCTs included in our review was generally low, with poor quality control over the lack of allocation concealment mechanism and blinding, which often introduces selection bias in the design and execution of a clinical trial.

4.2. Practical implications

One of the notable strengths of TCEs is that they can be implemented without the need for equipment, large exercise spaces, or intensive safety monitoring and supervision that are often required in other exercise interventions (e.g., resistance training, aerobic exercise). Thus, TCEs hold great potential for scaling up dissemination efforts across communities for diabetic care and diabetes prevention. Although TCEs are highly promising from a public health viewpoint, we still do not know what constitutes an appropriate exercise dose to achieve optimal benefits in glycemic control. Similarly, little is known regarding whether the duration of exercise programs

(short or long term) is associated with producing a uniform effect on glycemic biomarkers, including HbA1c and fasting blood glucose. Increasing our knowledge in these areas will be of high importance in developing clinical guidelines for diabetic care and management.

5. Conclusion

TCEs, such as Tai Ji Quan, Ba Duan Jin, and Qigong, are shown to be effective for type 2 diabetic individuals in lowering their risk of metabolic complications, compared with either a control or other form of care. Although our results add to the growing body of evidence supporting the use of TCEs to optimize reductions in markers of glycemic control, further studies to better understand the optimal dose and duration of exposure to TCE interventions are warranted.

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Authors' contributions

XW and GS conceived of the study; JZ and LC contributed to gathering information on the study and data extraction; CC and DZ assisted in the search process for studies. All authors participated in drafting the manuscript, read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

Supplementary material

Supplementary data to this article can be found online at [doi:10.1016/j.jshs.2018.08.004](https://doi.org/10.1016/j.jshs.2018.08.004).

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