

Whole-body vibration training – better care for COPD patients: a systematic review and meta-analysis

Jian Zhou^{1,2,*}

Long Pang^{2,*}

Nan Chen^{1,2}

Zihuai Wang^{1,2}

Chengdi Wang³

Yang Hai^{1,2}

Mengyuan Lyu^{2,4}

Hongjin Lai²

Feng Lin^{1,5}

¹Department of Thoracic Surgery, West China Hospital, Sichuan University, Chengdu, People's Republic of China; ²West China School of Medicine, Sichuan University, Chengdu, People's Republic of China; ³Department of Respiratory Medicine, Sichuan University, Chengdu, People's Republic of China; ⁴Department of Laboratory Medicine, West China Hospital, Sichuan University, Chengdu, People's Republic of China; ⁵Western China Collaborative Innovation Center for Early Diagnosis and Multidisciplinary Therapy of Lung Cancer, Sichuan University, Chengdu, People's Republic of China

*These authors contributed equally to this work

Correspondence: Feng Lin
Department of Thoracic Surgery,
West China Hospital, Sichuan University,
No 37, Guoxue Alley, Chengdu, Sichuan
610041, People's Republic of China
Tel +86 28 8542 2494
Fax +86 28 8542 2494
Email linfeng0220@aliyun.com

Purpose: Whole-body vibrating training (WBVT) is a modality aiming to improve neuromuscular performance of patients with COPD. However, a consensus on the effects of WBVT has not been reached. We aimed to clarify the effects of WBVT on functional exercise capacity, pulmonary function, and quality of life in COPD patients.

Patients and methods: PubMed, Web of Science, and EMBASE were searched through April 5, 2018. We calculated the pooled weight mean difference (WMD) using a random-effects model. Quality assessment and publication bias analyses were also performed.

Results: We included eight randomized control trials involving 365 patients. Compared with control group, WBVT increased 6-minute walking distance (6-MWD) (WMD: 62.14 m; 95% CI: 48.12–76.16; $P < 0.001$), the change of 6-MWD ($\Delta 6$ -MWD) (WMD: 42.33 m; 95% CI: 15.21–69.45; $P = 0.002$), the change of the time to finish five repeated sit-to-stand tests (WMD: –2.07 seconds; 95% CI: –4.00 to –0.05; $P = 0.04$), and decreased the change of St George's Respiratory Questionnaire score (WMD: –6.65 points; 95% CI: –10.52 to –2.78; $P < 0.001$). However, no significant difference was found between the two groups regarding forced expired volume in 1 second (FEV_1) (% predicated), change of FEV_1 (% predicated), sit-to-stand test, 6-MWD (% predicated), change of 6-MWD (% predicated), St George's Respiratory Questionnaire score, COPD Assessment Test score, and change of COPD Assessment Test score.

Conclusion: WBVT has beneficial effects on functional exercise capacity for COPD patients.

Keywords: COPD, whole-body vibration training, functional capacity, pulmonary rehabilitation

Introduction

Vibration is a mechanical stimulus, and the biomechanical variables that determine its intensity are the frequency and amplitude. Vibration training is the deliberate exposure to the body of varying frequencies using certain joint angles for any limited time. Vibration training is quite a new technology in sports science. Athletes and fitness and rehabilitation centers are widely using vibration training in their programs. Whole-body vibration training (WBVT) is one of the therapeutic pulmonary rehabilitation modalities aiming to improve neuromuscular performance of patients with neuromuscular dysfunction, which is applied through a vibration surface that generates sinusoidal vibrations.¹ During WBVT, muscle contraction is elicited, and selected muscles can thereby be stimulated and strengthened.²

WBVT devices deliver vibrations across a range of frequencies (15–60 Hz) and displacements from <1 to 10 mm. Numerous combinations of amplitudes and

frequencies with current technology make it possible for a wide variety of WBVT protocols to be used on humans. Vibrating platforms fall into different, distinct categories. The type of platform used is a moderator of the effect and result of the training or therapy performed. It can be pivotal (vibrating from side to side) or lineal (vibrating up and down). When applied in patients with COPD, it usually employs low-amplitude, low-frequency mechanical stimulation.

Roelants et al³ reported that after a 24-week WBVT, the muscle strength and performance of elderly women increased to a similar extent as regular resistance training. Evidence suggested that WBVT is a promising training modality for patients with COPD.⁴ However, a more convincing conclusion is urgently needed.

Our study aimed to identify the effects of WBVT on improving functional exercise capacity, pulmonary function, and quality of life in COPD patients.

Methods

Eligibility criteria

For inclusion, the studies needed to 1) focus on patients with COPD; 2) compare the effects difference between WBVT and conventional training; 3) be randomized controlled trials (RCTs); and 4) be written in English. The studies were excluded if they met one of the following criteria: 1) were reviews, letters, conference abstracts, book chapters, animal experiments, and case reports; 2) essential information was incomplete; and 3) WBVT was not conducted for the purpose of improving patient's condition. Two independent reviewers determined study eligibility.

Search strategy

Two authors (JZ and LP) independently searched literatures in MEDLINE, EMBASE, and Web of Science through April 5, 2018 with the following search items: "COPD" chronic obstructive pulmonary disease "emphysema" or "chronic bronchitis" and "whole body vibration training" "vibration training" or "vibration." Then, manual searching of the reference lists of eligible studies was done to find potential relevant publications.

Study selection

Two independent reviewers (JZ and LP) screened the titles and abstracts of identified articles. The obtained full-text of potential articles were screened for further check.

Data collection

Data extraction was performed by two independent researchers (JZ and LP), including publication information

(the first author, country, publication year), patient characteristics (sample size, age, gender, disease, the grade of COPD), WBVT training regime (the intensity, the frequency, the duration), and compared outcomes (6-minute walking distance [6-MWD], forced expiratory volume in 1 second [FEV₁], sit-to-stand test [SST], St George's Respiratory Questionnaire [SGRQ], COPD Assessment Test [CAT], Chronic Respiratory Questionnaire, Berg scale, and adverse events).

Risk of bias in individual studies

We assessed the risk of bias of included studies according the Risk of Bias Tool found in the *Cochrane Handbook for Systemic Reviews of Interventions*,⁵ with the following aspects: sequence generation and concealment of allocation (selection bias), blinding of participants and personnel (performance bias), blinding of outcome assessors (detection bias), incomplete outcome data addressed (attrition bias), free of selective reporting (reporting bias), and other bias. If any disagreements appeared, a third reviewer (FL) made a final decision.

Sensitivity analyses and subgroup analyses

We conducted sensitivity analyses to explore the potential reasons for the heterogeneity, by removing one included study each time and identifying the robustness of the results. Subgroups analyses were performed to find potential heterogeneity, including age (≥ 70 or < 70 years), ethnicity (European or American), the status of COPD (stable or severe), vibration type (side-alternating vibration or vertical vibration), and exercise duration (≥ 1 or < 1 month).

Synthesis of results

The pooled outcomes were expressed as weighted mean difference (WMD) with *P*-value and 95% CIs. The results were regarded statistically significant when $P < 0.05$. Heterogeneity across studies was tested by using the *I*² statistic, which is a quantitative measure of inconsistency across studies. Studies were considered to have low heterogeneity when *I*² statistic was 25%–50%, and those with an *I*² statistic $> 75\%$ were considered to have high heterogeneity. A random-effects model was used if the *I*² statistic $> 50\%$, otherwise the fixed-effect model was used. All statistical analyses were performed using Review Manager V.5.3 (The Cochrane Collaboration, Software Update, Oxford, UK).

Results

Study characteristics

A total of 1,012 studies were identified by the initial database search. Only eight RCTs⁶⁻¹³ with 365 patients were included in our study after full evaluation (Figure 1). The included studies were published between 2012 and 2017. The analyzed patients were mainly the elderly with an average age varying from 58 to 75 years, community dwelling, and functionally independent. People with exacerbated COPD were studied in one trial.⁹ Other trials studied individuals with stable COPD. Generally, no special intervention was performed in a control group, but three trials performed physiotherapy,⁹ calisthenics training,¹² and conventional resistance training,¹¹

respectively. The primary outcomes included 6-MWD, FEV₁, SST, SGRQ, CAT, CRQ, Berg scale, and the changes in these scores. Table 1 shows the study characteristics.

Methodological quality of included studies

The risk of the included studies was found to be acceptable. Three studies^{7,10,12} did not report the concealment of allocation. Due to the intervention (WBVT), it is not possible to blind patients or study personnel to the group allocation. All included studies did not report on any specific group being blinded in the articles, typically participants, personnel, and outcome assessors (Table 2 and Figure 2).

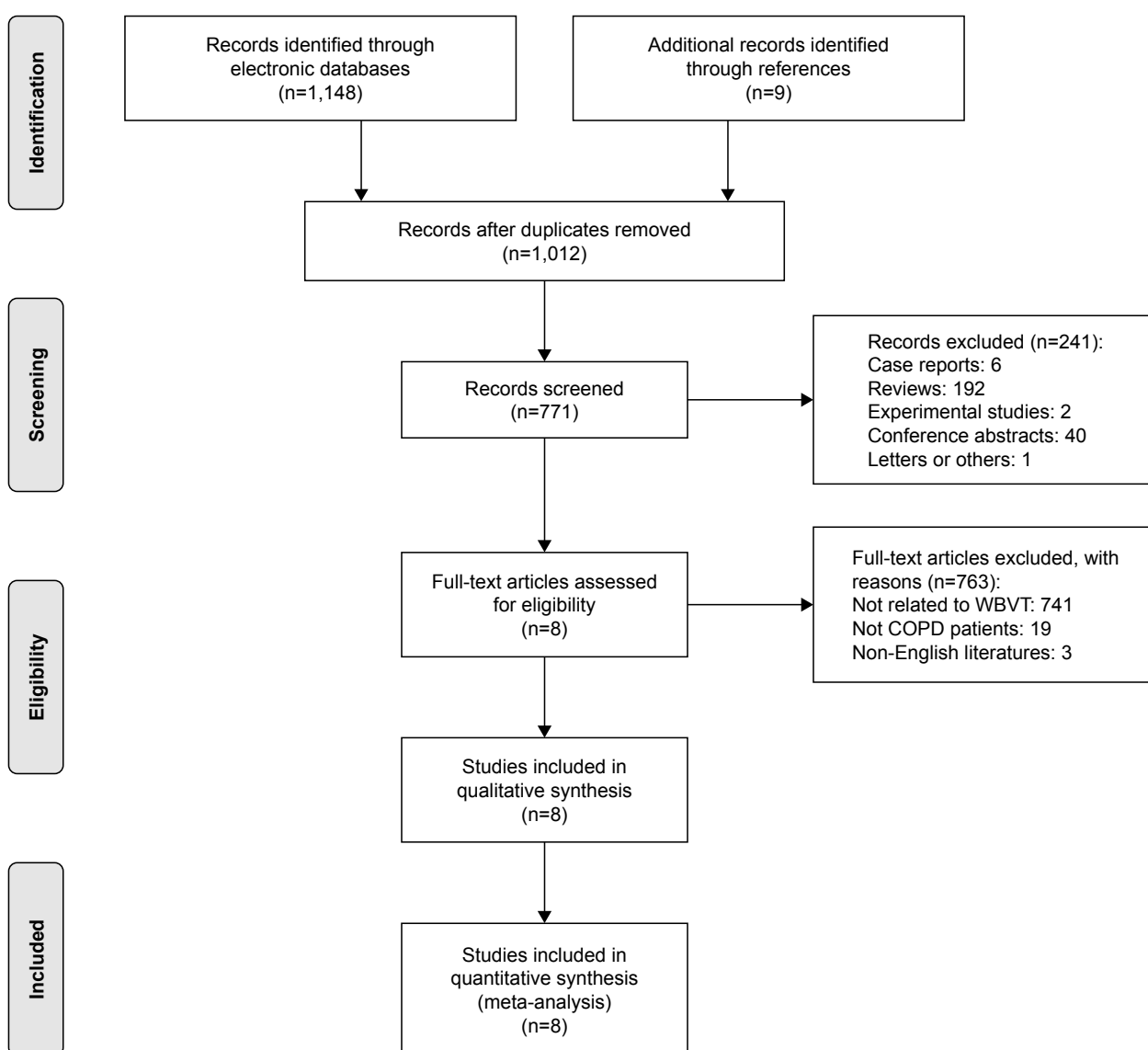


Figure 1 The PRISMA flow diagram of literature retrieval.

Note: Reproduced from Moher D, Liberati A, Tetzlaff J, Altman DG; The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med* 6(7):e1000097. doi:10.1371/journal.pmed1000097.³⁶

Abbreviation: WBVT, whole-body vibration training.

Table 1 Characteristics of the included RCTs

Study	WBVT group	Control group	Inclusion criteria	WBVT application	WBVT mode and settings	WBVT-related adverse events	WBVT exercise training regime	Findings
Gloeckl et al, ⁷ 2012	36 Age: 64±11 FEV ₁ (% pred): 39±11	36 Age: 65±7 FEV ₁ (% pred): 38±12	1) Assured diagnosis of COPD stage III or IV according to GOLD, 2) given written informed consent	9 sessions/ (3 sessions/ week for 3 weeks)	Side-alternating WBVT platform, 24–26 Hz, 6 mm peak-to-peak displacement	None reported	WBVT group: 3×3 minutes of self-paced dynamic squatting exercise during WBVT Control group: 3×3 minutes of self-paced dynamic squatting exercise on the floor without WBVT	WBVT seems to be a promising new exercise modality for patients with COPD and may enhance the effects of a multidisciplinary rehabilitation program
Pleguezuelos et al, ¹⁰ 2013	26 Age: 68.4±8.9 FEV ₁ (% pred): 37.11±11.9	25 Age: 71.3±8 FEV ₁ (% pred): 32.0±6.8	1) Severe COPD defined as FEV ₁ /FVC <0.7/FEV ₁ <50% predicted, 2) stable disease, 3) hospital admission or change in treatment in the previous 3 months	18 sessions/ (3 sessions/ week for 6 weeks)	Side-alternating WBVT platform, 35 Hz, 2 mm peak-to-peak displacement	None reported	WBVT group: six series, of four 30 seconds repetitions with 60 seconds of rest between each series Control group: 30 minutes of moderate intensity daily walking	WBVT significantly improved the functional capacity of severe COPD patients
Greulich et al, ⁹ 2014	20 Age: 66.4±9.93 FEV ₁ (% pred): 32.71±13.18	20 Age: 70.4±10.1 FEV ₁ (% pred): 38.4±17.82	1) Hospitalized due to severe COPD exacerbations, 2) pneumonia was ruled out by chest X-ray	Related to hospitalized days	Not mentioned	None reported	WBVT group: supervised manner 3×2 min/d on the vibrating platform with physiotherapy program Control group: physiotherapy program (5 minutes mobilization, 5 minutes passive movement, and 10 minutes respiratory exercises)	WBVT is safe, feasible, and may exhibit positive effects on clinical parameters in COPD patients hospitalized due to an exacerbation of their underlying disease
Braz Júnior et al, ⁶ 2015	11 Age: 62.9±8.82 FEV ₁ (% pred): 14.63±11.14		1) Diagnosis of COPD according to GOLD, 2) FEV ₁ <30% predicted, 3) stable disease, 4) smoking history, environmental or occupational exposure to pollutants, former smoker for at least 1 year, 5) a sedentary lifestyle and preserved cognitive functioning	36 sessions/ (3 sessions/ 12 week)	Side-alternating WBVT platform, 35 Hz, 2 mm (low intensity)/4 mm (high-intensity) peak-to-peak displacement	None reported	WBVT group: 30 seconds of semi-squatting training interspersed with 60 seconds of standing rest. 60 seconds of semi-squatting training interspersed with 30 seconds of standing rest Control group: no intervention	WBVT may potentially be a safe and feasible way to improve functional capacity in the 6-MWT of patients with COPD undergoing a training program on the vibrating platform as well as in all domains of the SGRQ quality of life
Salhi et al, ¹¹ 2011	26 Age: 58±4.5 FEV ₁ (% pred): 38±4.25	25 Age: 63±2.75 FEV ₁ (% pred): 39±4	1) Either the FEV ₁ <50% pred or diffusion capacity (DLCO) <50% pred, 2) W _{max} <90 Watt, a 6-MWWD <70% pred a QoL <100 points on the CRDQ or <20 points on the domain dyspnea of the CRDQ, 3) a QF <70% pred or respiratory muscle force <70% pred	36 sessions/ (3 sessions/ week for 12 weeks)	Side-alternating WBVT platform, 27 Hz, 2 mm peak-to-peak displacement	Comparable to previous studies.	WBVT group: 30–60 seconds lower-body exercises and upper-body exercises on WBVT on top of 15 minutes endurance training RT group: muscle training on multigym equipment with endurance training	WBVT after 15 minutes aerobic training enhances 6-MWWD, W _{max} , and QoL in COPD patients

<p>Spielmanns et al.¹² 2017</p>	<p>14 Age: 69±1.925 FEV₁ (% pred): 63±7.925</p>	<p>13 Age: 70±3 FEV₁ (% pred): 52±7.5</p>	<p>1) Stable COPD in stage I–III according to the GOLD classification, 2) written informed consent, 3) age ≥65 years 4) no involvement in any kind of regular exercise training (at least once per week) within the last 3 months before study</p>	<p>26 sessions (2 sessions/week during 3 months)</p>	<p>Side-alternating WBVT platform, 6–10 Hz (1–4 weeks)/12–18 Hz (5–8 weeks)/21–24 Hz (9–12 weeks), 2–6 mm peak-to-peak displacement</p>	<p>None reported</p>	<p>WBVT group: 10 minutes warm-up +15 minutes WBVT +5 minutes cool-down, training was performed for 3×2 minutes Calisthenics group: 30 minutes of relaxation and breathing retraining in combination with calisthenics exercises</p>	<p>A low-volume WBVT program resulted in significantly and clinically relevant larger improvements in exercise capacity compared with calisthenics exercises in subjects with mild-to-severe COPD WBVT may be highly beneficial when incorporated into PR programs for COPD patients, especially in those with impaired balance performance and low exercise capacity WBVT was feasible and safe in patients with COPD during an outpatient low-frequency exercise program</p>
<p>Gloeckl et al.⁸ 2017</p>	<p>36 Age: 65±8 FEV₁ (% pred): 25.2±5.2</p>	<p>36 Age: 63±9 FEV₁ (% pred): 36.6±11.7</p>	<p>Patients aged 50–80 years with COPD stage III or IV according to GOLD</p>	<p>9 sessions (3 sessions/week for 3 weeks)</p>	<p>Side-alternating WBVT platform, 24–26 Hz, 5 mm peak-to-peak displacement</p>	<p>None reported</p>	<p>WBVT group: squat exercise on WBVT with endurance training and strength training Control group: squat exercise without WBVT with endurance training and strength training</p>	<p>WBVT may be highly beneficial when incorporated into PR programs for COPD patients, especially in those with impaired balance performance and low exercise capacity WBVT was feasible and safe in patients with COPD during an outpatient low-frequency exercise program</p>
<p>Spielmanns et al.¹³ 2017</p>	<p>12 Age: 62.4±20.3 FEV₁ (% pred): 48.4±20.9</p>	<p>16 Age: 68.0±9.1 FEV₁ (% pred): 51.2±17.3</p>	<p>1) Patients with COPD at stages II–IV according to GOLD guideline, 2) they had to participate in pre- and postassessments at the outpatient center</p>	<p>13 sessions (1 session/week for 3 months)</p>	<p>Side-alternating WBVT platform, 24–26 Hz, 3 mm peak-to-peak displacement</p>	<p>During or after the training</p>	<p>WBVT group: 90 minutes squat exercises on WBVT Control group: 90 minutes squat exercises without WBVT</p>	<p>WBVT was feasible and safe in patients with COPD during an outpatient low-frequency exercise program</p>

Abbreviations: 6-MWD, 6-minute walking distance; WBVT, whole-body vibration training; GOLD, Global Initiative for Chronic Obstructive Lung Disease; PR, pulmonary rehabilitation; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; SGRQ, St. George's Respiratory Questionnaire; W_{max}, maximal workload; QoL, quality of life; CRDQ, Chronic Respiratory Disease Questionnaire; QF, quadriceps force; RT, resistance training.

Table 2 Risk of bias assessment

	Sequence generation	Concealment of allocation	Blinding of participants and personnel	Blinding of outcome assessors	Incomplete outcome data addressed	Free of selective reporting	Other bias
Gloeckl et al, ⁷ 2012	Low	Low	Low	Low	Low	Low	Low
Pleguezuelos et al, ¹⁰ 2013	Low	Unclear	Low	Low	Low	Low	Low
Greulich et al, ⁹ 2014	Low	Low	Low	Low	Low	Low	Low
Braz Júnior et al, ⁶ 2015	Low	Low	Low	Low	Low	Low	Low
Salhi et al, ¹¹ 2015	Low	Low	Unclear	Unclear	Low	Low	Low
Spielmanns et al, ¹² 2016	Low	Unclear	Unclear	Unclear	Low	Low	Low
Gloeckl et al, ⁸ 2017	Low	Low	Low	Low	Low	Low	Low
Spielmanns et al, ¹³ 2017	Low	Low	Low	Low	Low	Low	Low

Sensitivity analysis and publication bias

We did not find any outcomes that were outside of the estimated range from derived forest plots. No significant outcomes were found in sensitivity analyses. No significant publication biases were identified by Begg's test and visual inspection of the funnel plot.

Assessment of functional exercise capacity

6-MWD and the change of 6-MWD

6-MWD and its variation- change of 6-MWD were reported in all eight trials, as shown in Figure 3. The results showed a significantly increased 6-MWD result (WMD: 62.14, 95% CI: 48.12–76.16, $P<0.001$) and the change of 6-MWD (WMD: 42.33, 95% CI: 15.21–69.45, $P=0.002$) in WBVT group compared with control group, which indicated that WBVT led to significant improvements in functional exercise capacity. We found no significant discoveries in subgroup analyses. Side-alternating vibration was applied in five trials,^{7–9,12,13} in which 6-MWD did not show significant differences between two groups (WMD: 38.91, 95% CI: –1.11 to 78.92, $P=0.11$), but the change of 6-MWD (WMD: 43.73, 95% CI: 14.84–72.62, $P=0.003$) increased above the minimal clinically important difference (MCID) of 35 m.¹⁵ Vertical vibration was applied in the remaining three trials,^{6,10,11} but patients enrolled in these trials did not show any improvement in their 6-MWD (WMD: 38.66, 95% CI: –47.22 to 125.54, $P=0.38$) and change of 6-MWD (WMD: 40.51, 95% CI: –40.49 to 121.52, $P=0.33$) significantly.

6-MWD (% predicated) and change of 6-MWD (% predicated)

Three studies^{7,11,12} focused on 6-MWD (% predicated) to assess the functional exercise capacity. Compared with control group, WBVT group did not show a significantly increased 6-MWD (% predicated) (WMD: 4.21, 95% CI: –8.42

to 16.84, $P=0.51$) and the change of 6-MWD (% predicated) (WMD: 4.87, 95% CI: –5.19 to 14.93, $P=0.34$).

SST and change of SST

A total of five studies^{7–9,12,13} reported SST and the change of SST. The analysis of SST and the change of SST are presented in Figures 3 and 4. WBVT group decreased the change of SST significantly compared with control group (WMD: –2.07 seconds, 95% CI: –4.09 to –0.05, $P=0.04$). However, no significant outcome was found between the two groups regarding the SST (WMD: –1.45 seconds, 95% CI: –3.71 to 0.80, $P=0.21$). Side-alternating vibration was applied in all the five trials, and it decreased the change of SST above the MCID of 1.7 seconds.¹⁶

Assessment of pulmonary function

FEV₁ (% predicated) and change of FEV₁ (% predicated)

With analysis from three included studies,^{7,9,13} no significant difference was found between the two groups concerning FEV₁ (% predicated) (WMD: –0.95, 95% CI: –5.50 to 3.60, $P=0.68$), which can be seen in Figure 4, and the change of FEV₁ (% predicated) (WMD: –1.83, 95% CI: –4.53 to 0.87, $P=0.18$).

Assessment of quality of life

SGRQ and change of SGRQ

The change of SGRQ and SGRQ scores were reported in three trials.^{6,9,12} Compared with control group, WBVT decreased the change of SGRQ score (WMD: –6.65 points, 95% CI: –10.52 to –2.78, $P<0.001$). However, as is shown in Figure 4, no significant difference was found between the two groups regarding SGRQ score (WMD: –5.79 points, 95% CI: –13.16 to 1.58, $P=0.12$).

CAT and change of CAT

With analysis from three included trials,^{9,12,13} no significant difference was found between the two groups regarding

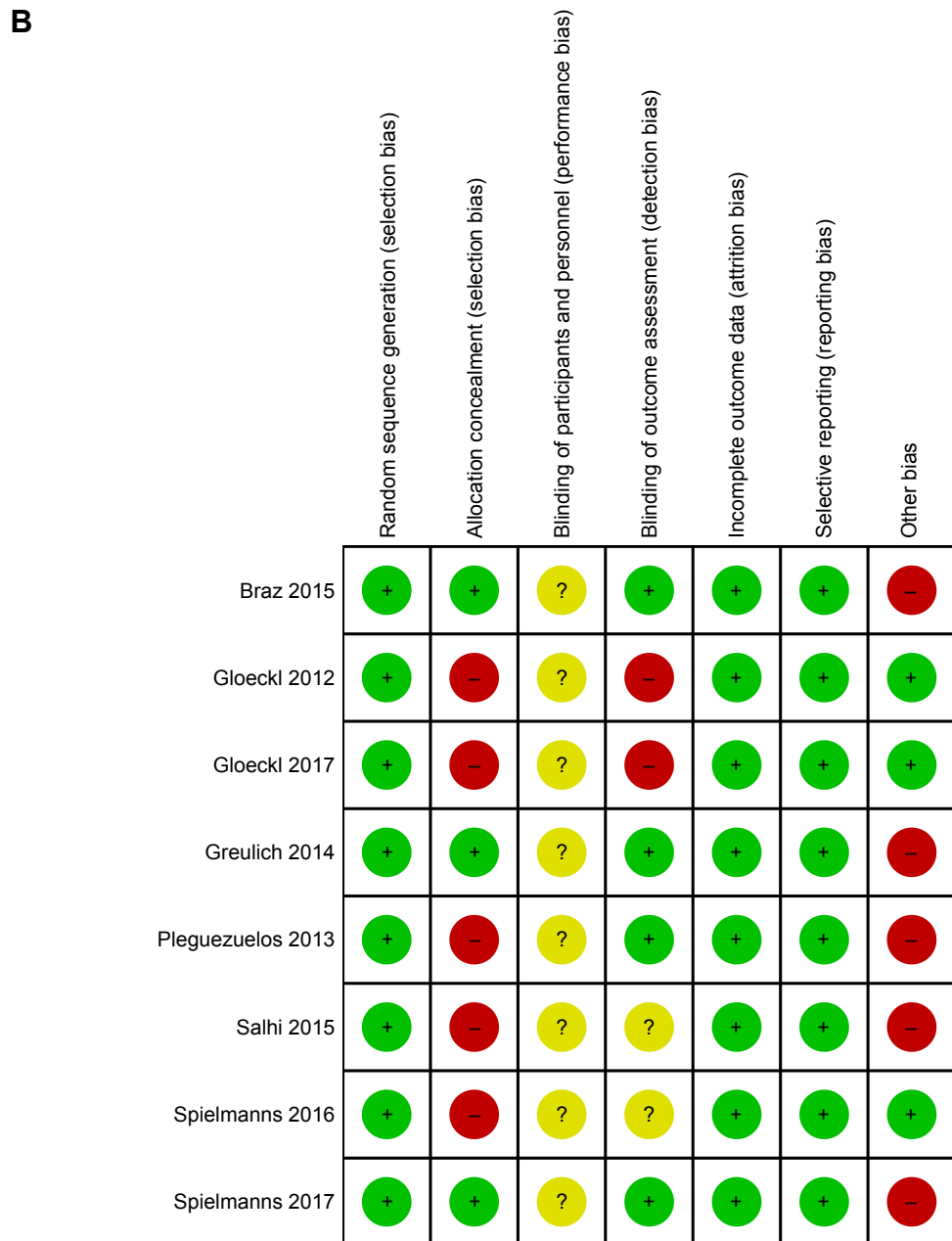
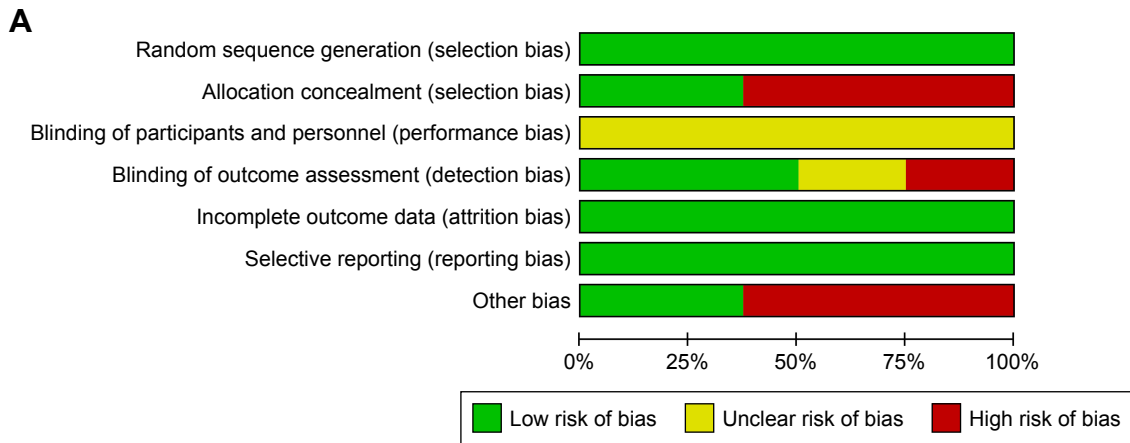


Figure 2 Assessment of risk of bias.

Notes: (A) Graph of the risk of bias for the included studies, (B) graph of the risk of bias summary for the included studies.

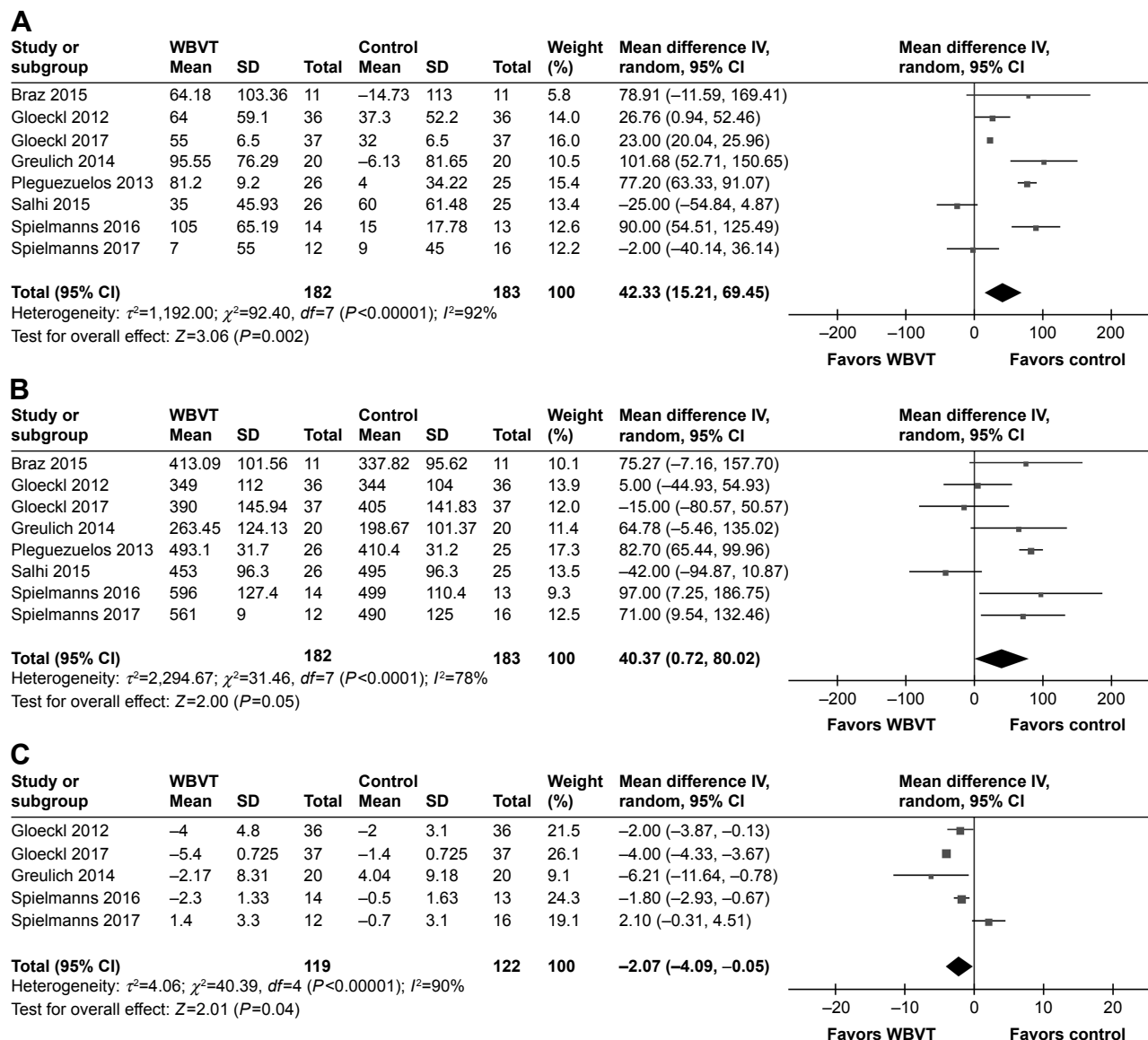


Figure 3 Meta-analysis of the effect of WBVT or control group on (A) change of 6-MWD; (B) 6-MWD; (C) change of SST.
Abbreviations: 6-MWD, 6-minute walking distance; SST, sit-to-stand test; WBVT, whole-body vibration training.

the CAT score (WMD: 1.35 points, 95% CI: -1.56 to 4.27, $P=0.36$) and the change of CAT score (WMD: -0.29 points, 95% CI: -3.27 to 2.69, $P=0.85$).

CRQ and change of CRQ

Change of CRQ and CRQ were reported in two trials;^{7,11} however, no significant difference was found between the two groups regarding the CRQ (WMD: 0.95, 95% CI: -0.64 to 2.54, $P=0.24$) and the change of CRQ (WMD: 0.27 points, 95% CI: -1.41 to 1.96, $P=0.75$).

Change of Berg scale and Berg scale

Based on the analysis of the two included studies,^{10,12} we found no significant difference between WBVT group and

control group regarding the Berg scale (WMD: 0.27 points, 95% CI: -1.37 to 1.92, $P=0.74$) and the change of Berg scale (WMD: 1.49 points, 95% CI: -3.10 to 6.09, $P=0.52$).

Discussion

Our study included eight RCTs to assess the efficacy and safety of WBVT in improving functional exercise capacity, pulmonary function, and quality of life in COPD patients. The present systematic review showed that WBVT had beneficial effects on functional exercise capacity, which was mainly measured by 6-MWD and change of 6-MWD. However, limited evidence suggested that WBVT might enhance pulmonary function and quality of life in COPD patients regarding the change of FEV₁ (% predicated) and SGRQ score.

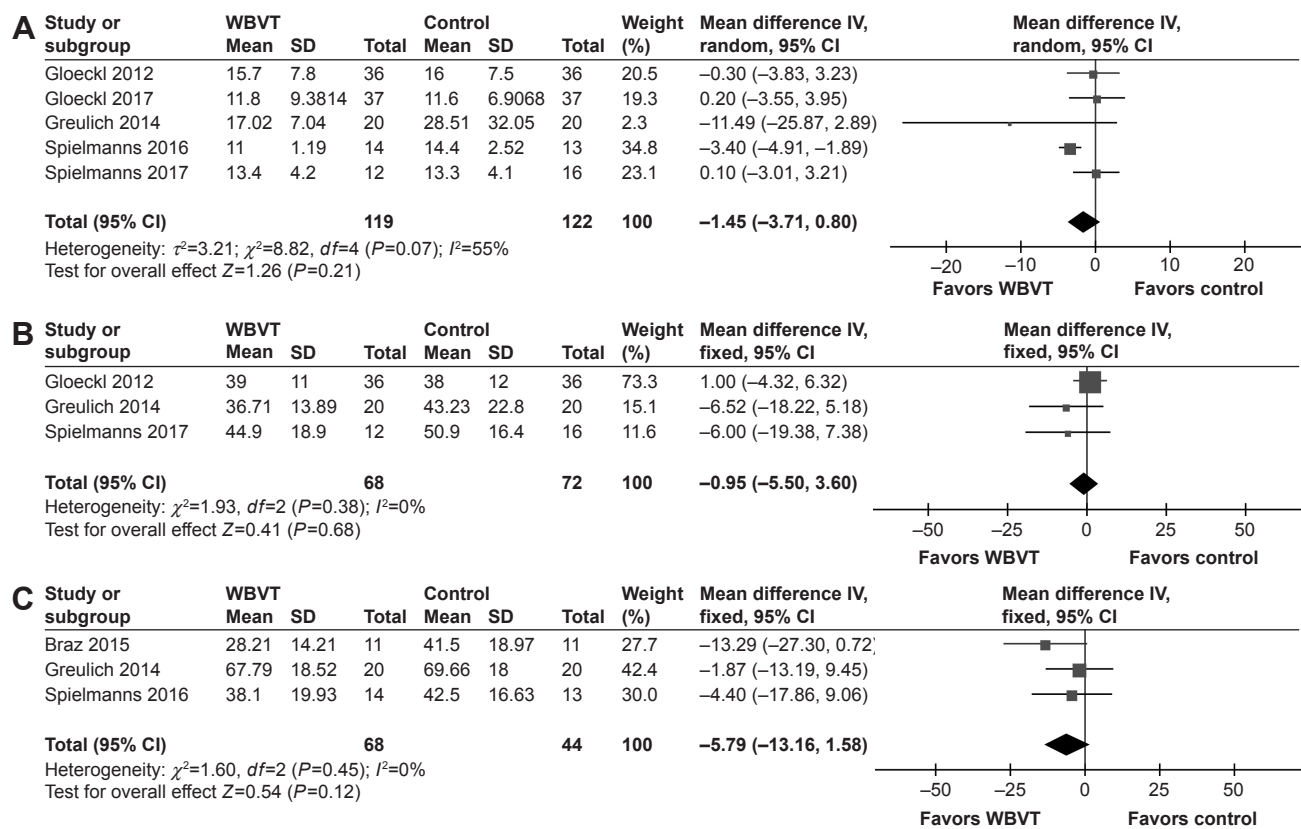


Figure 4 Meta-analysis of the effect of WBVT or control on (A) SST; (B) FEV₁ (% predicated); (C) SGRQ. **Abbreviations:** FEV₁, forced expiratory volume in the first second; SGRQ, St George's Respiratory Questionnaire; SST, sit-to-stand test; WBVT, whole-body vibration training.

Some previous systematic reviews¹⁷⁻¹⁹ focused on the question of whether WBVT was better than conventional training in pulmonary function and exercise capacity. Gloeckl et al¹⁷ performed a systematic review in 2015 which included six studies.^{6,7,9,10,20,21} However, we found that two of six included studies^{20,21} might not be RCTs. Yang et al¹⁸ and Cardim et al¹⁹ performed similar systematic reviews in 2016. The two systematic reviews performed by them included the same four RCTs.^{6,9,10,22} They both drew the conclusion that WBVT may improve functional exercise capacity of patients with COPD.

Compared with the previous systematic reviews, our present systematic review has some advantages. First, we included eight RCTs based on strict inclusion criteria, with a total of 365 patients enrolled. Second, we analyzed more outcomes, such as the change of 6-MWD, to measure the differences. Last but not the least, we performed more subgroup analyses, leading to new significant findings such as the fact that the type of WBVT influences the effects of training. These are the main advantages of this meta-analysis.

To clarify the effects of WBVT on functional exercise capacity, we used 6-MWD, the change of 6-MWD, 6-MWD

(% predicated), the change of 6-MWD (% predicated), and SST and the change of SST. 6-MWD and the change of 6-MWD were the most important outcomes showing significant differences. Patients enrolled in this meta-analysis increased their 6-MWD above the MCID of 35 m.¹⁵ Similar results were observed for the SST and SGRQ; the time needed for SST decreased above the MCID of 1.7 seconds.¹⁶ FEV₁ (% predicated) and the change of FEV₁ (% predicated) were used to measure the pulmonary function of COPD patients. Our results showed that no significant difference was found between the two groups, which indicated that WBVT provided limited benefits to pulmonary function. The change of SGRQ, SGRQ; the change of CAT, CAT; the change of CRQ, CRQ; and the change of Berg scale, Berg scale were used to measure the quality of life in COPD patients. Only the change of SGRQ decreased above the MCID of 4.²³ Considering a reduction in quality of evidence due to the risk of bias, the inaccuracy and inconsistency, it is hard to draw the conclusion that WBVT has benefits on the quality of life in COPD patients.

The underlying mechanisms by which WBVT improves muscle function are incompletely clarified. During WBVT,

the vibrations are transmitted to the muscle group through the limbs, which motivates the activation of the active muscle and improves the biological activity of the high threshold motion unit, leading to the participation of the muscle group in the sports unit.²⁴ The effects of WBVT therapy can be divided into two types: direct biological effect and indirect biological effect. Direct effects derive from the mechanical vibration waves to the muscle group. Indirect effects are connected to the reflex and regulation of nerve and body fluids caused by mechanical vibration waves. The mechanism by which WBVT can improve functional exercise capacity of people with COPD might be closely related to the following factors.

First, WBVT led to improvements in neuromuscular activation. The most common mechanism to explain WBVT-induced reflex muscular activity is the tonic vibration reflex.²⁵ Different from the voluntary muscle control in traditional resistance training, the muscle contractions during WBVT are stimulated by stretch reflexes.²⁶ The length of the muscle spindle generally increases and afferents from Golgi tendon organs become more sensitive to vibration,²⁵ which is seen as an effective measurement of tendon elongation and a surrogate of force.²⁷ People feel an experience of movement during the tonic vibration reflex,²⁸ in which the discharge from Golgi tendon organs increases, which means better muscle force.²⁵ Furthermore, specific increases in ATP turnover and a generation of excess heat follow vibrations to fiber preparations,²⁴ which is complied with increased skin and muscle perfusion.^{29–31}

Second, WBVT improves blood circulation in people with COPD. At present, the relevant literature shows that after WBVT, the peripheral blood circulation of the body increases by nearly 14%.³² WBVT can increase the amount of vascular endothelial growth factor and endothelia in blood, thus accelerating blood vessel formation.³³ WBVT can also effectively improve the dilatation capacity of arterioles,³⁴ the speed of the blood flow, the flexibility and coordination of the muscle and also reduce the threshold of the excitability of the muscle spindle at the same time,³⁵ which shows important physiological significance to indirectly improve the exercise capacity of people with COPD.

Furthermore, the effects of WBVT on the respiratory system are mostly focused on alleviating the clinical symptoms of lung diseases. WBVT can effectively improve the clinical symptoms of patients with COPD, which is mainly related to the strengthened contraction force of the respiratory muscles, which further stimulates the respiratory function, improves the ratio of ventilation, blood flow, and the respiratory function.^{7,10} Taking all related factors together, WBVT can effectively improve the muscle performance.

Our results showed heterogeneity across included studies. We concluded the possible reasons of heterogeneity as follows. First, the severity of participants' state of COPD ranged from stable to severe, so different stages of COPD could result in the heterogeneity. Second, the various assessments of effects of WBVT could contribute to the heterogeneity. Furthermore, inhomogeneous study protocols and settings (study period, WBVT device, WBVT parameters, exercises performed on the WBVT platform, age of patients) made the heterogeneity inevitable.

To clarify the origin of heterogeneity, we tried to perform subgroup analyses. The type of vibration was an important factor related to the effects of WBVT. Side-alternating vibration increased the change of 6-MWD and decreased the change of SST above the MCID, but vertical vibration did not lead to any significant difference. Subgroup analyses showed that side-alternating vibration may be better than vertical vibration. Also, WBVT had different effects on patients at different age, but not those of different ethnicity. Besides, people with stable COPD benefited more than people with severe COPD. However, the limited sample made it hard to decide whether longer training period would have greater effects.

The first potential limitation of this present systematic review was the different training protocols and inconsistent control group interventions used among studies, which contributed mostly to the heterogeneity of the outcomes. Another limitation is that due to limited intention-to-treat data reported, our primary analysis was not according to intention-to-treat analyses, which may bias our results.

Conclusion

In conclusion, the current evidence indicates that WBVT is a safe modality that has beneficial effects on functional exercise capacity but limited effects on pulmonary function and quality of life of COPD patients. More high-quality RCTs are needed to confirm this.

Acknowledgment

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Author contributions

FL, JZ, and LP conceived and designed the study. FL provided administrative support. Provision of study materials or patients was due to JZ. JZ and LP helped in the collection and assembly of data. JZ, LP, NC, ZW, CW, YH, ML, and HL were involved with data analysis. FL, JZ, LP, NC, ZW, CW, YH, ML, and HL were involved in manuscript writing and final approval of the paper. All authors contributed

toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure

The authors report no conflicts of interest in this work.

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