REVIEW ARTICLE (META-ANALYSIS)

Therapeutic Effects of Whole-Body Vibration Training in Knee Osteoarthritis: A Systematic Review and Meta-Analysis

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Abstract
Objective: To examine the current evidence regarding the effects of whole-body vibration (WBV) training in individuals with knee osteoarthritis (OA).

Data Sources: We searched PubMed, CINAHL, Embase, Scopus, Physiotherapy Evidence Database (PEDro), and Science Citation Index for research articles published prior to January 2015 using the keywords whole body vibration, vibration training, and vibratory exercise in combination with the Medical Subject Heading osteoarthritis knee.

Study Selection: This meta-analysis was restricted to randomized controlled trials published in the English language. The quality of the selected studies was assessed by the PEDro Scale. The risk of bias was assessed using the Cochrane collaboration's tool in the domain-based evaluation. We also evaluated the quality of each study based on the criteria given by the International Society of Musculoskeletal and Neuronal Interactions for reporting WBV intervention studies, consisting of 13 factors.

Data Extraction: Descriptive data regarding subjects, design, intervention, WBV parameters, outcomes, and conclusions were collected from each study by 2 independent evaluators. The mean and SD of the baseline and final endpoint scores for pain, stiffness, and function were extracted from the included studies.

Data Synthesis: A total of 83 studies were found in the search. Of these, 5 studies met the inclusion criteria and were further analyzed. Four of these 5 studies reached high methodologic quality on the PEDro Scale. Overall, studies demonstrated mixed results in favor of additive effects of WBV for reducing pain and improving function in knee OA. There was considerable variation in the parameters of the WBV included in this systematic review.

Conclusions: WBV training reduces pain and improves function in individuals with knee OA.

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Knee osteoarthritis (OA) is the most common form of degenerative joint disease affecting both men and women. In addition to pain, knee OA causes joint stiffness and decreased quadriceps strength resulting in physical disability. The target of any treatment approach in the management of knee OA includes reduction of pain, disability, and improvement in quadriceps muscle strength. Currently accepted nonpharmacologic treatment options for OA recommended by the Osteoarthritis Research Society International include patient education, weight loss, physical rehabilitation, exercise, change in activities of daily living, and coping strategies.

Recently, the use of whole-body vibration (WBV) has been recommended as an efficient and alternative option for improving muscle strength in individuals with knee OA. Other studies demonstrated improvement in the function and self-reported disease status in individuals with knee OA after a 12-week training program of squatting exercise combined with WBV. However, Trans et al reported no improvement in self-reported knee pain and function, which shows that there is no consistent finding on this issue.
WBV training is the exercise program performed with the body on a platform that generates vibrations. These vibrations are transmitted to the body and stimulate the primary endings of the muscle spindles, thereby activating γ-motor neurons, which cause muscle contractions similar to the tonic vibration reflex. WBV training can be given via 2 types of machines, the rotational vibration and vertical vibration machines. Rotational vibration machines can vibrate in 2 dimensions (right and left), whereas vertical vibration machines can vibrate in all 3 spatial dimensions. The study suggests that it is easier to maintain the correct training posture on a vertical vibration machine than a rotational vibration machine.

Recently, Wang et al published a systematic review and meta-analysis to investigate the effects of WBV on pain, stiffness, and physical functions in individuals with knee OA. They reported that the WBV training program significantly improves physical functions, but there is no evidence that WBV can reduce pain and stiffness in individuals with knee OA. However, because this review compared posttest data, there is a possibility that the group variations in the baseline data can affect the results. Therefore, the comparison of mean differences between groups would give more reliable results. In addition, the use of the International Society of Musculoskeletal and Neuronal Interactions (ISMNI)–recommended criteria would improve the quality of reports about WBV treatment studies.

Therefore, the objective of this systematic review is to provide an overview of current available evidence regarding the therapeutic effects of WBV training in individuals with knee OA.

Methods

Data sources

The search for published studies was conducted using PubMed, CINAHL, Embase, Scopus, Physiotherapy Evidence Database (PEDro), and Science Citation Index using a combination of the keywords whole body vibration, vibration therapy, and vibratory exercise with osteoarthritis knee and the Medical Subject Headings osteoarthritis, knee combined with whole body vibration or vibration. The bibliographic search was restricted to randomized controlled trials (RCTs) published in the English language prior to January 2015. Hand searching of the identified studies was used to find other appropriate studies. Two independent evaluators (S.A., H.Z.) selected the studies based on titles and abstract, excluding those articles not related to the objectives of this review.

Study selection

The meta-analysis was restricted to RCTs published in the English language prior to January 2015. Trials were required to compare exercise with and without WBV or compare exercise with WBV and a control. Studies that did not include WBV therapy in their interventions were excluded. The outcome measures of interest were pain, stiffness, and function in individuals with knee OA. RCTs were excluded if the publication was in abstract form only.

Assessment of methodologic quality

Two independent reviewers (S.A., H.Z.) assessed the quality of the included studies using the PEDro Scale. The scale consists of 11 questions to assess the quality of RCTs on 2 aspects, including internal validity (criteria 2–9) and sufficient statistical information to make it interpretable (criteria 10 and 11). Each question is scored according to its presence or absence in the assessed study. The sum of all positive responses gives the final score.

The studies with a score ≥5 (50%) were considered high quality, as reported by Moseley et al. Therefore, in the present review, all randomized studies with scores ≥5 (5/10) were considered to be of high methodologic quality. Two evaluators independently assessed methodologic quality using the PEDro Scale.

The risk of bias was assessed using the Cochrane collaboration’s tool in the domain-based evaluation. The assessed domains were sequence generation, allocation concealment, blinding, completeness of outcome data, and absence of selective outcome reporting. Risk of bias was classified as low, unclear, and high in each domain.

In addition, we also evaluated the quality of each study based on the criteria given by the ISMNI for reporting WBV intervention studies, consisting of 13 factors. We evaluated whether each article adequately described the 13 questions inquiring about the WBV parameters (eg, frequency, amplitude, acceleration) and participants’ position (eg, holding on to a railing, exercise position, footwear condition). Each of these factors was scored with yes, no, or unclear, based on the descriptions. If the displacement was not described as peak-to-peak, the vibration amplitude was scored as unclear. If figures in the articles show participants holding onto a railing and footwear conditions, we scored these with a yes.

Data analysis

The selected studies were screened by 2 independent evaluators (S.A., H.Z.). The analysis of included studies was performed according to a structured script using the following parameters: author/year, subjects, design, intervention, WBV parameters, outcomes, and conclusions. Disagreements between the evaluators were resolved by discussion to reach consensus. The unweighted κ was used to determine the agreement between the 2 evaluators.

The outcome measures of interest were pain, stiffness, and function. The mean and SD of the baseline and final endpoint scores for pain, stiffness, and function were extracted from the included studies. The mean change score (final score – baseline score) for each outcome measure was calculated for each intervention. The standardized mean difference for the outcomes (pain, stiffness, function) was computed using Hedges (adjusted) g (g = M1 – M2 / S_pooled, where M1 and M2 are the mean change scores of groups 1 and 2, respectively, and S_pooled is the estimate of the population SD). The magnitude of the effect size was categorized using the Cohen categories, with g < 0.5 as a small effect size; g ≥ 0.5 and ≤ 0.8 as a medium effect size; and g > 0.8 as a large effect size. The random effects meta-analysis was conducted to determine the overall effect size of WBV. Then 95% confidence intervals (CIs)

**List of abbreviations:**

- CI: confidence interval
- ISMNI: International Society of Musculoskeletal and Neuronal Interactions
- OA: osteoarthritis
- PEDro: Physiotherapy Evidence Database
- RCT: randomized controlled trial
- WBV: whole-body vibration
- WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index
were calculated for effect sizes based on a generic inverse variance outcome model. The significance of the overall effect was tested using the $z$ statistic. The Cochran Q statistic and Higgins $I^2$ statistic were used to determine statistical heterogeneity between studies. A low $P$ value ($\leq 0.10$) for the Q statistic was considered evidence of heterogeneity of treatment effects. All statistics were computed using Comprehensive Meta-Analysis software.

**Results**

**Identified studies**

The initial search resulted in 83 research studies. A total of 65 studies that appeared in $>1$ database or did not meet predetermined inclusion criteria were excluded. A total of 18 studies

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**Table 1** Methodologic classification assessed by the PEDro Scale

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Simão et al$^6$</th>
<th>Trans et al$^5$</th>
<th>Avelar et al$^{11}$</th>
<th>Tsuji et al$^7$</th>
<th>Park et al$^8$</th>
<th>Cumulative Score$^*$</th>
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<td>5</td>
<td>4</td>
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$^*$ Out of the 5 total studies.

$^1$ Maximum score of 10.

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Fig 1 Flow diagram of the study procedure.
were assessed for eligibility. Thirteen studies were eliminated because they did not match the inclusion criteria or were not available in full text (fig 1). The final selection, made by consensus, resulted in the inclusion of 5 studies in the quality assessment phase.

**Quality assessment of study**

The 5 included studies had an average PEDro score of 5.6 out of 10, as illustrated in table 1. These scores represent multiple sources of bias that may skew the results. The most common shortcomings were lack of blinding (patient, therapist, assessor), follow-up, intention-to-treat analysis, and concealed allocation. The most adhered to items on the PEDro Scale were random allocation, baseline comparability, measurements of variability, and between-group comparison, which were evident in almost all of the trials. Most studies seemed to suggest a favorable additive benefit after WBV with exercise for pain and function compared with the control.

Agreement between evaluators was excellent (unweighted \( \kappa = .88 \)) in assessing risk of bias across studies. Table 2 details the risk of bias assessment of the included studies. The overall risk of bias assessment indicated that the risk of bias was low in 1 study, high in 3 studies, and unclear in 1 study.

The quality score of each study followed by the ISMNI recommendation is shown in table 3. The overall mean score was 6.8±0.84 (range, 6–8) of 13 points. All included studies gave the brand name and type of vibration device used. None of the included studies clearly described that the given amplitude was peak to peak.

**Characteristics of the study populations**

The participant characteristics are given in table 4. The sample size ranged from 23 to 47, with the mean age varying from 60 to 75 years. Most of the studies included only women participants with knee OA. Most of the studies used clinical and radiographic criteria of the American College of Rheumatology to diagnose knee OA. One study used the Kellgren and Lawrence scale to assess severity of knee OA.

**Training protocol**

The training protocols are summarized in table 4. Three studies used vertical vibration, whereas others did not specify the type of vibration used. Four studies had a frequency of 3 sessions per week, whereas 1 study had 2 sessions per week. Three studies had 8 weeks duration of treatment, whereas 2 studies had 12 weeks of treatment. The frequency and amplitude of the vibration signals used varied from 12 to 40Hz and 2 to 5mm, respectively. The frequency of vibration was increased from 35 to 40Hz in 2 studies, 30 to 40Hz in 1 study, 25 to 30Hz in 1 study, and 12 to 14Hz in 1 study during treatment duration. One study did not specify the amplitude used.

The number of vibration bouts delivered per sessions varied from 1 to 9 for a period that lasted for 20 seconds to 10 minutes for each. Two studies had vibration bouts of 6 to 8 repetitions for 20 to 40 seconds for each. One study had vibration bouts of 1 to 2 repetitions for 30 to 60 seconds for each. 1 study had 6 to 9 repetitions for 30 to 70 seconds, and 1 study had 2 repetitions for 10 minutes for each.

**Outcome measures**

The outcome measures of interest were pain, stiffness, and function in individuals with knee OA. Three studies used the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain score, 1 study used the numerical rating scale, and 1 study used the Japanese Knee Osteoarthritis Measure pain score for measuring pain. One study used the Japanese Knee Osteoarthritis Measure, 1 study used the Korean WOMAC, and others used the WOMAC for measuring stiffness and function.

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**Table 2** Risk of bias of included studies

<table>
<thead>
<tr>
<th>Citations</th>
<th>adequate sequence generation</th>
<th>allocation concealment</th>
<th>blinding</th>
<th>incomplete outcome data addressed</th>
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<td>Park et al</td>
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**Table 3** Methodologic assessment by the recommendations of the ISMNI

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<th>q4</th>
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<td>Trans et al</td>
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**Table 4** Training protocol

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**Table 5** Outcome measures

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<tr>
<td>Simão et al⁹</td>
<td>Knee OA based on clinical and radiographic criteria of ACR</td>
<td>Group 1: 75 (18/82) Group 2: 71 (9/91)</td>
<td>RCT</td>
<td>1: Squat-WBV (n=12) 2: Control (n=12)</td>
<td>Frequency (Hz): 35, 40 Amplitude (mm): 4Acceleration (g):2–2.61</td>
<td>3 times a week, 12wk</td>
<td>WOMAC</td>
<td>The addition of vibration training to squat exercise reduces the self-perception of pain. No significant differences between groups were observed on functional scores.</td>
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<tr>
<td>Trans et al⁶</td>
<td>Knee OA based on clinical and radiographic criteria of ACR</td>
<td>Group 1: 61.5 (0/100) Group 2: 61.1 (0/100)</td>
<td>RCT</td>
<td>1: WBV-exercise on stable platform (n=17) 2: Control (n=18)</td>
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<td>2 times a week, 8wk</td>
<td>WOMAC</td>
<td>No significant differences between groups were observed on pain and functional scores.</td>
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<td>Avelar et al¹⁰</td>
<td>Knee OA based on clinical and radiographic criteria of ACR</td>
<td>Group 1: 75 (18/82) Group 2: 71 (10/90)</td>
<td>RCT</td>
<td>1: Squat-WBV (n=12) 2: Squat (n=11)</td>
<td>Frequency (Hz): 35, 40 Amplitude (mm): 4 Acceleration (g): 2.78–3.26</td>
<td>3 times a week, 12wk</td>
<td>WOMAC</td>
<td>The addition of vibration training to squat exercise does not reduce pain and improve function beyond that of squat exercise without WBV.</td>
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<td>Tsuji et al⁷</td>
<td>Postmenopausal women with knee pain in the age group of 50–75y Knee OA based on KL scale (0–4)</td>
<td>Group 1: 62.1 (0/100) Group 2: 60.9 (0/100)</td>
<td>RCT</td>
<td>1: Accelerated training: WBV (n=32) 2: Control: home exercise (n=15)</td>
<td>Frequency (Hz): 30, 40 Amplitude (mm): 2.5 Acceleration (g): NR</td>
<td>3 times a week, 8wk</td>
<td>JKOM</td>
<td>The accelerated training program consisting of strength and flexibility training with WBV-reported improvement in function. No significant differences between groups were observed on the pain score.</td>
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<td>Park et al⁸</td>
<td>Knee OA based on clinical and radiographic criteria of ACR</td>
<td>Group 1: 62.5 (0/100) Group 2: 60 (0/100)</td>
<td>RCT</td>
<td>1: WBV and home exercise (n=17) 2: Control: home exercise (n=19)</td>
<td>Frequency (Hz): 12, 14 Amplitude (mm): 2.5–5 Acceleration (g): NR</td>
<td>3 times a week, 8wk</td>
<td>NRS KWOMAC</td>
<td>The WBV with home exercise group reported significant reduction in pain compared with home exercise alone. No significant differences between groups were observed on function.</td>
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Abbreviations: ACR, American College of Rheumatology; JKOM, Japanese Knee Osteoarthritis Measure; KL, Kellgren and Lawrence; KWOMAC, Korean Western Ontario and McMaster Universities Osteoarthritis Index; NR, not reported; NRS, numerical rating scale.
Effect of WBV on pain
Meta-analysis of 5 trials showed that most studies displayed an insignificant effect size point estimate to favor WBV compared with the control; however, the test for an overall effect across the 5 included studies was significant ($P=0.016$), with an overall small effect size point estimate of $0.40 (95\% CI, 0.08–0.73)$ based on a fixed-effects model that favored WBV compared with the control. Therefore, WBV was effective in reducing pain (fig 2). No significant heterogeneity was found ($I^2=0\%, P=0.558$).

Effect of WBV on stiffness
Meta-analysis of 5 trials showed that all studies displayed an insignificant effect size point estimate to favor WBV compared with the control; the test for an overall effect across the 5 included studies was insignificant ($P=0.193$), with an overall small effect size point estimate of $0.21 (95\% CI, -0.11 to 0.54)$ based on a fixed-effects model. Therefore, WBV compared with the control was not effective at reducing stiffness (fig 3). No significant heterogeneity was found ($I^2=0\%, P=0.809$).

Effect of WBV on function
Meta-analysis of 5 trials showed that most studies displayed an insignificant effect size point estimate to favor WBV compared with the control; however, the test for an overall effect across the 5 included studies was significant ($P=0.024$), with an overall small effect size point estimate of $0.37 (95\% CI, 0.05–0.70)$ based on a fixed-effects model. Therefore, WBV compared with the control was effective at improving function (fig 4). No significant heterogeneity was found ($I^2=52.22\%, P=0.079$).

Discussion
The present review evaluated 5 RCTs including a total of 165 participants to examine evidence regarding the therapeutic effect of WBV in the management of knee OA. Among the 5 studies evaluated using the PEDro Scale, \(^\text{14}\) 4 were considered of high methodologic quality. Of the 5 included studies, 3 studies would be regarded as high risk of bias because they failed to fulfill the required criteria. \(^\text{15,16}\) Our evaluation showed that more than half of the studies performed adequate random sequence generation;
however, blinding of the outcome assessment was unclear (see table 2).

Per the guidelines given by the ISMNI recommendations, 17 some factors related to the acceleration were not sufficiently documented in the included studies. Only 2 studies measured the actual acceleration of the WBV platform and described the method used to ensure consistent targeting amplitude of the WBV.9,10 The acceleration generated by the WBV platform is one of the most salient factors in WBV studies; therefore, future studies should strictly adhere to these guidelines. 32

The methodology and procedures of the intervention of the evaluated studies were properly prepared and described, allowing for clinical reproducibility. The use of the ISMNI recommended criteria and the Cochrane collaboration’s tool to assess the risk of bias gives additional strength and improves the quality of this review about WBV treatment studies.

On the basis of the present review, WBV along with exercises compared with the control has shown a greater reduction of pain and improvement in function. However, the present review did not find any additional effect of WBV on stiffness compared with the control. Similarly, Yoon et al30 reported significant improvement of function after WBV training in middle-aged and older Japanese women with knee OA and knee pain. Another study reported that WBV training yields similar results to traditional strength training for reduction of pain in individuals with knee OA. 31

Recently in a systematic review and meta-analysis, Wang 13 reported that the WBV training program significantly improved physical functions, but in contrast with the present study, there was no evidence that WBV can reduce pain in individuals with knee OA. These differences in the results may be caused by the methodologic differences we adopted in this review. In the present review, the mean change score (final score minus baseline score) for each outcome measure was compared; however, Wang compared posttest data, and there is a possibility that the group variations in the baseline data can affect the results. In addition, the present review included 1 more trial, which could have caused this result. 7

Most studies reported a priori sample size calculation to determine the minimum number of subjects necessary for each group for adequate power. Although there was some variation in the methods and interventions used in these studies, overall the studies demonstrated mixed results in favor of additive effects of WBV for reducing pain and improving function in knee OA. There was variation in the content and duration of the exercise programs included in our systematic review. The length of intervention ranged from 8 to 12 weeks, with a frequency of intervention ranging from 2 to 3 times per week. There was considerable variation in the parameters of the WBV included in our systematic review. Variations among the 5 studies included duration of intervention; type of control groups; and vibration parameters, including frequency, amplitude, and acceleration.

**Study limitations**

There are several limitations in the present review. Three out of the 5 studies included only participants who were women. Additionally, in this review, no study assessed the isolated effect of WBV on outcome. For example, it is undetermined whether isolated WBV would yield similar or better effects than when using WBV in combination with another intervention. This would be an important area of research to determine the clinical effectiveness of WBV. Moreover, different vibration platforms have different technical characteristics and may induce different therapeutic effects. None of the selected studies attempted to compare the effects of different vibration platforms. Furthermore, none of the selected studies evaluated long-term follow-up effects of WBV on outcome. In addition, the present study did not suggest optimal vibration parameters because of variations in the methodologies.

**Conclusions**

WBV has demonstrated limited but beneficial therapeutic effects in individuals with knee OA. WBV training reduces pain and improves function in individuals with knee OA. In the present review there is a variation in the vibration protocol, training dose, and reported results. Therefore, more robust, well-designed studies are required for conclusive evidence of the beneficial therapeutic effects of WBV training in individuals with knee OA.
a. Comprehensive Meta-Analysis; Biostat.

Keywords
Knee; Osteoarthritis; Pain; Rehabilitation; Vibration

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