This is a pre-copyedited, author-produced version of an article accepted for publication in Physical Therapy following peer review. The version of record Lin-Rong Liao, Meizhen Huang, Freddy M.H. Lam, Marco Y.C. Pang, Effects of Whole-Body Vibration Therapy on Body Functions and Structures, Activity, and Participation Poststroke: A Systematic Review, Physical Therapy, Volume 94, Issue 9, 1 September 2014, Pages 1232–1251 is available online at: https://doi.org/10.2522/ptj.20130366.

Title: The effects of whole body vibration therapy on body functions and structures, activity and participation post-stroke: a systematic review

Authors:

LIAO Lin-Rong (MPT)[1,2], HUANG Meizhen (BSc)[2], LAM Freddy MH (BSc)[2], PANG Marco Y. C. (PhD)[2]

Affiliations:

[2]Department of Physiotherapy, Guangdong Provincial Work Injury Rehabilitation Hospital, Guangzhou, China

[1]Department of Rehabilitation Sciences, the Hong Kong Polytechnic University, Hong Kong

Running head: Whole body vibration and stroke

Address for correspondence:

Marco Y.C. Pang, Ph.D.

Department of Rehabilitation Sciences, Hong Kong Polytechnic University, Hung Hom, Hong Kong.

Phone: 852-2766-7156

Fax: 852-2330-8656

E-mail: Marco.Pang@polyu.edu.hk

Funding: This study is substantially supported by the General Research Fund provided by the Research Grants Council (no. PolyU 5245/11E).

Conflict of interest: All authors declare no conflict of interest.

Abstract

Background: Whole body vibration (WBV) has gained increasing popularity in rehabilitation. Recent studies have seen the application of WBV in individuals with chronic illnesses, including stroke.

Purpose: To compare WBV exercise with (1) the same exercise condition without WBV, (2) other types of physical exercise in enhancing body functions and structures, activity and participation in individuals with stroke, and examine its safety.

Data source: Electronic search were conducted on MEDLINE, CINAHL, PEDro, PubMed, PsycINFO, Science Citation Index.

Study Selection: Randomized controlled trials (RCTs) that investigated the effects of WBV among individuals with stroke were identified by two independent researchers. Ten articles (nine studies) totaling 333 subjects satisfied the selection criteria and were included in this review.

Data extraction: The methodological quality was rated using the PEDro scale. The results were extracted by two independent researchers and confirmed with the principal investigator.

Data Synthesis: Only two RCTs were considered as level 1 evidence (PEDro score ≥6 and sample size >50). Two RCTs examined the effects of a single WBV session whereas seven examined the effects of WBV programs spanning 3-12 weeks. No consistent benefits on bone turnover, leg motor function, balance, mobility, sensation, fall rate, activities of daily living, and societal participation were found, regardless of the nature of the comparison group. Adverse events were **not uncommon but minor**.

Limitations: A broad approach was used, with stroke as an inclusion criterion for review. **No solid evidence was found concerning the effects of WBV on sub-groups of people with specific stroke-related deficits due to the heterogeneity of patient groups.**

Conclusions: Clinical use of WBV in enhancing body functions/ structures, activity and participation after stroke is not supported.

Word count: 4498

In the past decade, whole body vibration (WBV) therapy has gained increasing popularity in rehabilitation of different patient populations. The use of local muscle vibration has long been used in physical therapy to stimulate muscle activity.[1] In the 1990s, muscle vibration was used during weight training to enhance muscle strength and power.[2,3] Later, WBV platforms, which are capable of generating mechanical vibrations at different frequencies and magnitude, were developed, and have been widely used to enhance muscle performance in athletes,[4] young adults[5,6] and older adults[7]. Typically, individuals are asked to perform both static and dynamic exercises while receiving WBV, in order to train up muscle strength in both types of contraction.[8-11] Numerous studies have shown that muscle activation level, as measured by electromyography (EMG), is substantially enhanced when WBV is added during exercise.[12-14] In addition to inducing reflex muscle activity,[1,10,15] there is also evidence that WBV can modulate the excitability of the spinal motorneuronal pool and corticomotor neurons.[16-18] These physiological phenomena may be some of the mechanisms underlying the WBV-induced improvement in neuromuscular functions reported in previous studies.

The rapid development of WBV applications in humans in recent years also stems from animal research in the 1990s and 2000s, which found that high-frequency dynamic mechanical loading is a potent stimulus for bone formation.[19-21] Since then, different WBV protocols have been developed in various animal models, with promising results.[22-24] These findings had led to a surge of research efforts in exploring the use of WBV to enhance bone mass in people at risk of developing osteoporosis, such as individuals during prolonged bed rest[25], postmenopausal women and older adults.[7]

Recent meta-analyses have suggested that WBV has beneficial effects on some aspects of muscular strength, balance and mobility function in older adults while its effect on bone tissue is rather inconclusive.[7,26-28] **WBV** research incorporating outcomes related to societal participation and quality of life is scarce.[29] Additionally, it is uncertain which combinations of WBV frequencies and amplitudes are most effective in improving various outcomes.[7,26]

In the past few years, researchers have begun to explore the application of WBV in individuals with chronic illnesses.[30-32] The potential use of WBV in stroke has also aroused great research interest. **A systematic review was thus undertaken to examine the effect of WBV in people with stroke. In this review, we adopted a framework based on the International Classification of Functioning, Disability and Health (ICF) model endorsed by the World Health Organization.[33] It is known that the deficits in functioning at the level of body functions and structures post-stroke (e.g., muscle weakness, spasticity, cognitive deficits, etc.) may not only interact with each other to produce problems with execution of tasks such as walking and other activities of daily living (i.e. activity), but also impose restrictions on the ability to partake fully in various life situations (i.e., participation).[34,35] When evaluating a rehabilitative intervention, it is important to assess its effects on all 3 different levels of functioning, as a holistic approach in patient care is essential.[36]**

This systematic review aimed to examine the effects of WBV therapy on body functions and structures, activity and participation in individuals with stroke.[37-46] To examine the safety of WBV applications in people with stroke, adverse events associated with WBV training were also reviewed.

METHOD

Research question

The objective of this systematic review was defined using the PICO method.[47] ***PATIENTS (P)***: individuals with stroke; ***INTERVENTION (I)***: WBV therapy; ***COMPARISON (C)***: (1) **WBV compared to** no WBV under the same exercise condition, (2) **WBV compared to** other types of physical activity or training; ***OUTCOMES (O)***: body functions and structures, activity and participation. Two **comparisons** were used, because WBV training has two components, namely, vibratory stimulation, and exercises while standing on the platform. Using **comparison** (1) would allow the delineation of effects of the vibratory stimulation alone, while **comparison** (2) would enable us to determine whether the WBV exercise approach as a whole would be a viable alternative to common practice or other types of exercise. Thus, this systematic review aimed to answer the following question: does WBV therapy lead to better outcomes in body functions and structures, activity and participation when compared with no vibration under the same exercise condition or other forms of exercise among individuals with stroke?

Study selection

The inclusion criteria were randomized controlled trials (RCTs) that investigated the effects of WBV among individuals with stroke; included body functions and structures, activity, or participation as one of the outcome measures; were published in English. Articles were excluded if they were research studies on the effects of WBV in individuals with a primary diagnosis other than stroke (e.g. arthritis, etc.); reports in books or conference proceedings.

Data sources and searches

An extensive literature search of electronic databases, including MEDLINE (1950–7 May 2013), Cumulative Index to Nursing and Allied Health Literature (CINAHL) (1982–7 May 2013), PubMed and PsycINFO (1806+) were performed. The specific search strategy for the MEDLINE database is described in Appendix 1 (supplementary material). A similar search strategy was used for other databases. In addition, the Physiotherapy Evidence Database was searched using the keyword "vibration".[48] The review protocol can be obtained by contacting the principal investigator (MYCP).

The titles and abstracts of the articles generated from the above search were screened to eliminate irrelevant studies. The full text of the remaining articles was then reviewed in detail to determine their eligibility. For each article that fulfilled the eligibility criteria, the reference list was also examined to identify other potentially relevant papers. Additionally, a forward search using the Web of Science was conducted on 5 October 2013 to indentify all relevant articles that referenced the selected articles. The article screening and selection was performed by two independent researchers (LRL, MZH) and any disagreement was resolved by discussion with the principal investigator (MYCP).

Methodological quality assessment

The PEDro scale was used to assess the scientific rigor of the selected studies (9–10: excellent; 6–8: good; 4–5: fair; <4: poor) (Table 1).[49] The PEDro score was obtained by searching the PEDro database.[48] Studies rated as good or excellent by PEDro and having a sample size >50 were considered as level 1 evidence while those of lower quality were considered as level 2 evidence (rated as fair or poor by PEDro, or sample size ≤50).[50]

Data synthesis and analysis

The effects of WBV on outcomes of interest were initially summarized by the first author (LRL). Next, two co-authors (MZH and FMHL) checked the accuracy of the data. Disagreements were settled by discussion with the principal investigator (MYCP) until a consensus was reached. After reviewing the results of the selected studies, it was decided that meta-analysis was not appropriate because only a few studies (<5) used the same outcome measures, and the treatment protocols also varied substantially across the different studies (i.e., heterogeneity). To estimate the size of the treatment effect for those outcomes that yielded significant results, the standardized effect size (SES) with Hedges' correction was computed using the mean and standard deviation (SD) of the change scores of the experimental and control groups (small SES = 0.2, medium = 0.5, large = 0.8).[51] If the mean or SD values of the change scores were not reported, the mean and SD values measured at post-test for the two groups were used to compute the SES.

RESULTS

Study selection

The flow of information through the different phases of the systematic review is described in Figure 1. The inter-rater agreement for article selection was excellent (Kappa=0.88). The reports by Lau et al.[41] and Pang et al.[42] were derived from the same trial. Overall, ten articles (9 studies) were selected for this systematic review (Table 1).

Quality of reviewed articles

We were able to retrieve the PEDro scores of other studies on the Physiotherapy Evidence Database website, except Tankisheva et al.[46] Therefore, this article was reviewed and scored independently by two research team members who were experienced with using the PEDro scale (LRL and MYCP). The results are displayed in Table 1. Overall, only two studies were considered as level 1 evidence (PEDro score ≥6 and sample size >50).[37,41,42] The rest of the RCTs were all considered as level 2 evidence.[38-40,43-46]

Participants

The characteristics of the study participants are outlined in Table 2. Five studies used individuals with chronic stroke (onset ≥ 6 months) in their samples.[41-46] People with sub-acute stroke were studied in four trials.[37-40] **There was a tendency for the participants in the chronic stroke trials to have more severe physical impairments than those in the subacute stroke trials (Table 2).**

Intervention protocol

WBV group

There were considerable differences in the WBV protocols adopted across the selected studies (Table 3). The frequency and amplitude of the vibration signals used were 5-45 Hz, and 0.44-5 mm, respectively. The peak vertical accelerations of the vibration platform covered a range from 0.2 to 15.8 units of *g* (Earth's gravitational constant) based on the theoretical relationship [peak acceleration= $(2\pi f)^2 A$], where f is the frequency and A is the amplitude of the vibration.[52] Six studies used synchronous vertical vibrations,[38,39,41-44,46] and two studies used side-alternating vertical vibrations.[37,45] One study used Vibrosphere® to deliver the WBV without specifying the vibration type.[40] The vibration was usually delivered in bouts, with intermittent short rest periods. The number of vibration bouts delivered varied vastly, ranging from 1 to 12, for a period between 15 seconds and 10 minutes each. Two studies assessed the immediate effects of a single WBV session, [38,44] while seven studies examined the effects of WBV after 3 to 12 weeks of treatment.[37,39-43,45,46] For the latter trials, the frequency of the training sessions varied from 1 to 5 sessions per week.

Five studies used only static exercises in WBV training.[37,38,43-45] The most common static exercises prescribed were semi-squat with knee flexion at 30° to 60° while standing on the WBV platform.[37,43-45] A combination of static and dynamic exercises was used in three studies,[40-42,46] whereas dynamic exercises alone were used in Tihanyi et al.[39] In three studies, the WBV group also received daily conventional rehabilitation in addition to WBV.[39,40,45]

Comparison group

Five studies incorporated an active exercise group which performed the same exercises while standing on the same platform as the WBV group but without vibration (4 studies)[38,41,42,44,45] or with sham vibration (1 study)[43] (Table 3)(i.e., **comparison** 1 as defined in Methods).[38,41,42,44,45] Four studies engaged the control group in different activities (e.g., conventional rehabilitation, exercise on music, habitual physical activity) (i.e., **comparison** 2 as defined in Methods).[37,39,40,46]

Effects of a single session of WBV intervention

Two studies involving 46 participants investigated the immediate effects of a single WBV session (Table 4).[38,44]

Body functions and structures

Leg muscle strength

Comparison 1: Tihanyi et al.[38] showed that the WBV group had a significantly more increase in isometric (SES=.50, $\boldsymbol{p}$=.03) and eccentric knee extension torque (SES=.46, $\boldsymbol{p}$=.04) on the paretic side. The co-activation of the antagonist muscle biceps femoris (BF) during maximal isometric (SES=.80, $\boldsymbol{p}$=.03) and eccentric knee extension (SES=.16, $\boldsymbol{p}$=.01) was also significantly less in the WBV group compared with controls.

Spasticity

Comparison 1: Inconsistent findings were reported in Chan et al.[44] Modified Ashworth Scale (MAS) ($\boldsymbol{p}\leq$.001) and visual analogue scale (VAS) scores (a measure of perceived spasticity; SES=1.96, $\boldsymbol{p}\leq$.001) **were reduced significantly more in the WBV group. The ratio between the maximum H reflex (i.e., reflex motor response of the tested muscle to stimulation of the**

type Ia afferents innervating the same muscle) and maximum M response (i.e., motor response of tested muscle to stimulation of motor nerve innervating the same muscle) of the gastrocnemius-soleus muscle, as recorded by electromyography, was also used as an index of excitability of the stretch reflex pathway. The Hmax/Mmax ratio decreased significantly more in the WBV group after the intervention period in the unaffected leg only (SES=.87, *p*=.03), indicating a decrease in excitability of the stretch reflex pathway. The change in this ratio showed no significant between-group difference in the affected leg. The change in amplitude of the Achilles deep tendon reflex also showed no significant between-group difference after treatment.

Postural control

Comparison 1: Chan et al.[44] showed that after WBV training, the percentage of total body weight borne by the affected leg had a significantly greater increase than the comparison group (SES=.87, ***p***=.02).[44]

Activity and Participation

Functional mobility

Comparison 1: Chan et al.[44] reported that the time taken to complete the Timed-Up-and-Go Test (TUG) was reduced significantly more in the WBV group than the comparison group after the treatment period (SES=1.80, *p*≤.001). The WBV group also improved more in maximum walking speed as measured in the 10-meter walk test (SES=.79, ***p***=.03), but not cadence (***p***=.10).[44]

Effects of multiple sessions of WBV intervention

Seven studies (287 participants) assessed the effects of WBV interventions spanning 3-12 weeks (Table 5).[37,39-43,45,46]

Body function and structures

Bone turnover

Comparison 1: Pang et al.[42] demonstrated no significant change in levels of C-telopeptide of type I collagen cross-links (CTx; a bone resorption marker) and bone-specific alkaline phosphatase (BAP; a bone formation marker) in both the treatment and control groups after 8 weeks.

Leg muscle strength/motor function

Comparison 1: No significant results in Chedoke McMaster Assessment (CMSA) score[42], isometric[40,43,45] and dynamic knee extension strength[42,43,45] were identified after WBV.

Comparison 2: Tihanyi et al.[39] reported that WBV was superior in improving isometric knee extension strength on both the paretic (SES=0.46, ***p***=.01) and non-paretic sides (SES=0.74, ***p***=.03). Tankisheva et al.[46] reported better improvement on the paretic side only (SES=1.74, ***p***=.04). For dynamic knee extension strength, Tihanyi et al.[39] reported significant results on both sides after WBV (paretic side: SES=.51, ***p***=.01; non-paretic side: SES=.51, ***p***=.02) while Tankisheva et al.[46] reported significantly better improvement on the paretic side at a contraction speed of 240°/s (SES=.96, ***p***=.04), but not 60°/s, at 12-week follow-up.[46] No significant between-group difference were reported for isometric and dynamic knee flexion torque (240°/s and 60°/s)[46] and Motricity Index.[37]

Muscle thickness

Comparison 1: The change in thickness of rectus femoris (RF), vastus lateralis (VL), and medial gastrocnemius (MG) muscles on both sides demonstrated no significant difference between the WBV and comparison groups, as determined by ultrasound.[45]

Spasticity

Comparison 1: Using MAS, Brogardh et al.[43] reported no significant treatment effect of WBV on leg spasticity. In contrast, Pang et al.[42] showed a decreasing trend in MAS score of the paretic knee in the WBV group, **but not the comparison group, after treatment. Post-hoc analysis of the WBV group data showed that** statistical significance was reached for the comparison between baseline and 1-month follow-up (***p*=.01**), but not for that between baseline and immediately after the 8-week training period. **No significant change of MAS score was observed at the ankle joint on the paretic side in both groups.[42]**

Comparison 2: Tankisheva et al.[46] reported no change in leg muscle spasticity after the intervention period in both groups.

Postural Control

Comparison 1: No significant results were found, regardless of the outcome measures used.[41,43,45]

Comparison 2: Out of three studies[37,40,46], only Tankisheva et al. [46] showed that WBV was superior. Significantly more improvement in the equilibrium score when standing on a sway-referenced support surface with eyes open (SES=1.47, p<.05) was reported in the WBV group, compared with habitual physical activity.[46] In the other two studies, similar and significant improvements in balance ability were reported in both the WBV and comparison groups.[37,40]

Falls

Comparison 1: Lau et al.[41] reported no significant difference in fall incidence during the 6-month follow-up period between the WBV and comparison group.[41]

Sensation

Comparison 2: The WBV and comparison groups had similar and significant improvement in somatosensory threshold in the affected leg. [37]

Activity and Participation

Functional mobility

Comparison 1: No significant treatment effect was found on TUG[43], comfortable gait speed[41,43], fast gait speed[43], and Six-Minute-Walk-Test (6MWT)[41,43].

Comparison 2: Out of two studies that measured mobility function[37,40], only Merkert et al.[40] reported that WBV was superior in improving TUG score (SES=.60, p=.01). Van Nes et al.[37], on the other hand, showed that mobility function (indicated by Rivermead Mobility Index and Functional Ambulation Categories) improved significantly to a similar extent in both groups.

Activities of Daily Living

Comparison 2: Merkert et al.[40] reported the superiority of WBV in improving the Barthel Index (BI) score (SES=.61, $\boldsymbol{p} \leq .01$) whereas van Nes et al.[37] showed similar and significant improvement in BI score in both treatment arms.

Stroke Impact Scale

Comparison 1: No significant change in the Stroke Impact Scale (SIS) score was found in both the WBV and sham vibration groups.[43]

Adverse events

A total of **168** participants were exposed to WBV in the nine studies included in this review. Five studies explicitly stated whether there were any adverse events [37,41-43,45,46] In Lau et al.,[41] 5 out of 41 participants in the WBV group reported adverse symptoms that were potentially related to WBV exposure, such as knee pain, fatigue, and dizziness. Brogardh et al.[43] reported that 15 out of 31 participants had transient mild muscle soreness or muscle fatigue, regardless of the group assignment (i.e., WBV or sham vibration). Tankisheva et al.[46] reported that some of the subjects experienced itching in the legs. **While adverse events were not uncommon, they were all mild and usually subsided after the first few sessions of training**. Two studies reported no adverse events in all subjects exposed to WBV (n=38).[37,45] It was not clear whether any adverse events occurred in four studies.[38,39,40,44]

DISCUSSION

This is the first systematic review to specifically examine the effects of WBV on body functions and structures, activity and participation in people with stroke. Overall, the WBV intervention is safe but no consistent benefits on bone turnover, leg motor function, balance, mobility, sensation, fall rate, activities of daily living, and societal participation were found.

Does vibratory stimulation alone confer any benefits?

By having the subjects in the comparison group perform the same activities without WBV or with sham vibration (**comparison** 1), the effects of the vibration stimuli on the following outcomes can be delineated in 5 studies.[38,41,42,43,44,45]

Body function and structures

Bone turnover

The review revealed that the effect of WBV on bone metabolism in individuals with stroke is far from conclusive, as only one study[42] measured biochemical markers of bone turnover and no significant results were identified. Examining the literature in older adults also provides little insight as to what WBV protocols may be the best in inducing favorable bone outcomes. A number of studies showed that WBV training did not induce any significant effects on bone turnover rate compared with other exercise training or no-intervention control.[53-55] Only

Turner et al.[56] showed that their 8-week WBV protocol (12Hz, 0.3*g*, 20 minutes per session with interspersed rest periods) resulted in a significant reduction in level of bone resorption marker (N-telopeptide X) in post-menopausal women, when compared with sham vibration exposure. Their protocol used a WBV frequency (12Hz), which was lower than that used by Pang et al.[42] and other studies (25-40Hz) in this review. Studying the effect of WBV on bone metabolism is an important question, as it is well documented that people with stroke sustain accelerated bone loss in the paretic limbs,[57] elevated bone resorption and reduced bone formation marker levels.[58] More research on WBV and bone health post-stroke is definitely needed.

Muscle structure and function

Although Tihanyi et al.[38] (level 2 study) demonstrated that WBV stimulation has additional effect on increasing knee muscle strength transiently after a single treatment session, no conclusion could be drawn because it was the only study that assessed this issue. In addition, out of the four studies that measured muscle strength or thickness after multiple WBV sessions, none showed significant results.[41,42,43,45] These findings may indicate that the vibration stimulation itself may not confer additional benefits on muscle strength/structure after stroke, although it cannot be ruled out that their protocols used may not be optimal to facilitate gain in these outcomes. The frequency range used in these four studies was 5-30Hz. A meta-analysis by Marin et al.[59] claimed that WBV frequencies of 35-40Hz are more effective than other frequencies (30-35 Hz and 40-45Hz) in inducing gain in muscle power. However, it is not clear whether the meta-analysis was preceded by a systematic review. The criteria for selection of articles were also not explicitly specified. For example, studies of different populations (e.g., young adults, athletes, older adults) or comparison groups might have been mixed together. It is not known whether only RCTs were included in their analysis. Inclusion of studies with poor scientific rigor may compromise the validity of the meta-analysis. Additionally, the effects of different vibration frequencies may also depend on the muscle group being stimulated.[12,13]

Spasticity

Previous studies in healthy individuals and people with spinal cord injury suggested that WBV may modulate the excitability of the spinal motorneuronal pool, as reflected by the amplitude of the H-reflex or Hmax/Mmax ratio.[60,61] Based on our review, the evidence on the effect of WBV on spasticity post-stroke is somewhat conflicting.

The evidence related to the transient effect of a single WBV session on spasticity is based on one level 2 study and thus not conclusive.[44] While the authors claimed that WBV significantly reduced spasticity,[44] the reported improvement in MAS and VAS scores was not accompanied by other measurements of spasticity (Table 4). In addition, the VAS is only a subjective measure and its improvement can be easily explained by the placebo effect of the added WBV, as the study participants were not blinded.

Of the two studies that measured spasticity after multiple sessions of WBV treatment,[42,43] only Pang et al.[42] (level 1 study) reported some beneficial effects on knee spasticity. This is somewhat intriguing, as spasticity at the ankle joint, which is typically more severe than that at the knee, was not modified by their WBV protocol. Taken together, there is no consistent evidence to show that WBV stimulation can reduce spasticity. A common drawback of these two studies is that MAS was the only measure used to evaluate spasticity. MAS may not be the best assessment tool because it is ordinal in nature, with only moderate reliability and correlation with muscle activity and resistance in response to passive movements,[62,63] making it difficult to detect significant changes in spasticity level. **The Modified Tardieu scale may be a better option to assess the effects of WBV on spasticity in future studies.[64]**

Postural control and falls

The beneficial effects of a single WBV session on postural control were supported by Chan et al. (level 2 study) only.[44] However, postural control was only assessed by a single measure (weight distribution between the two legs). The placebo effect of WBV could not be ruled out, as the participants were not blinded.

The evidence is also insufficient to support the use of longer-term WBV training in improving balance. Of the three studies, none found significant between-group difference in balance outcomes after a training period of 6 weeks to 3 months,[40,43,45] suggesting that WBV has no real effects on postural control in people with stroke. An alternative explanation of the non-significant results may be related to the psychometric properties of the outcome measure used. BBS was used as the main balance outcome in these three chronic stroke trials. While BBS is a common balance measure used in clinical practice, its ceiling effect is well documented.[65] In all three studies, the balance ability of the participants was quite good already before treatment, as confirmed by the baseline data showing a mean BBS score varying from 46.1 to 51.2 points.[41,43,45] This was probably due to the inclusion criteria used in these studies (e.g., able to remain standing without external support for at least 30 seconds,[45] ambulate independently for >100m[43])

(Table 2). BBS may thus be unable to detect changes in balance ability for these individuals who have only mild impairments in balance performance, thereby contributing to the negative results.

Only one study measured incidence of falls and reported negative results.[41] This is not surprising, given the lack of significant effects on neuromotor outcomes, and the fact that only a 10% of subjects had experienced at least one fall within 3 months before the training period. No recommendation can be made on the use of WBV to reduce fall rate after stroke.[41]

Activity and participation

Functional mobility

No firm conclusion can be derived from the available evidence to determine whether a brief WBV session has significant transient effect on mobility, as this topic was addressed by only one level 2 study.[44] Despite the positive results reported, their WBV group was substantially more impaired than the control group, as reflected by the considerably more time required to complete the TUG (mean difference=22 seconds) and 10-meter walk (mean difference=7 seconds) at baseline. The different mobility status of the subjects between the two groups may partially explain the difference in outcomes, as there may be more room for improvement in individuals with more severe limitations in mobility. The evidence is also inadequate to support the use of longer-term WBV training to improve mobility function post-stroke.[41,43] Based on the two studies that incorporated mobility outcomes, WBV stimulation was shown to confer no additional benefit on mobility function after chronic stroke. This is reasonable, as the various measures of body functions/structures that are highly related to mobility (e.g., muscle strength, postural control) were not influenced by WBV stimulation, as discussed above.

Societal participation

No conclusion can be drawn concerning the effects of WBV on particpation[43], as it was evalucated in one level 2 study only, with unremarkable results when compared with sham vibration.

Is WBV exercise approach as a whole a viable alternative to other forms of physical exercise?

Whether the WBV is superior to other forms of physical exercise (**comparison** 2) can be determined in 4 studies.[37,39,40,46]

Body function and structures

Muscle strength

Out of the three studies that addressed muscle strength[37,39,46], Tihanyi et al.[39] and Tankisheva et al.[46] (both level 2) reported better outcomes in the WBV group, whereas van Nes et al.[37] (level 1) reported comparable gain in muscle strength in the two groups. **Several reasons may explain the discordance in results.** First, the outcomes may be influenced by the interaction of many different factors, such as WBV protocols, subject characteristics and outcome measures used. As shown in Table 2, these factors demonstrated substantial diversity across the different studies. Upon closer examination of the data, we could not identify any specific trend that would explain the discrepancies in results. Second, the activities in the comparison group for the three studies were different, involving exercise on music[37], conventional exercise training[39], and habitual physical activity respectively[46]. Third, the total treatment time may be a confounding factor. For the two studies that demonstrated results in favor of WBV, the intervention group might have had additional treatment time due to WBV training.[39, 46] This is in contrast with van Nes et al.[37], in which the total treatment time was the same in the two groups. Based on the finding of Van Nes et al[37], one can argue that WBV exercise training as a whole may induce beneficial effects on muscle strength that are comparable to exercise on music. However, it cannot be determined whether the improvement in muscle strength detected in both groups was induced by the conventional exercise program (which both groups received) or the added WBV training or exercise on music.[37] Hence, it remains elusive as to whether WBV exercise training is a viable alternative to other forms of rehabilitative training to improve muscle strength post-stroke.

We do not have sufficient evidence to determine whether WBV is more effective in improving isometric muscle strength than dynamic (e.g., eccentric or concentric) strength. As demonstrated by Tankisheva[46], the outcome may also be highly dependent upon other factors as well, including functional role of the muscle (e.g., flexor Vs extensor), baseline muscle strength and contraction speed.

Spasticity

There is insufficient evidence to support or refute the notion that WBV is beneficial in reducing spasticity compared with other forms of exercise, as only one level 2 study addressed this issue and no significant change in leg muscle spasticity was found in both groups after the 6-week intervention period.[46]

Postural control

Two studies showed that WBV training yielded similar results on postural control when compared with other types of physical activity.[37,40] However, the WBV group had received more treatment time, which might have confounded the results.[37,40] Superiority of WBV training over habitual physical activity was reported by Tankisheva et al.[46], in which the WBV group had more improvement in equilibrium score when standing on a sway-referenced platform. The authors, however, offered no convincing explanation why improvement was observed only in this variable, out of the many balance outcomes used. Thus, it remains uncertain whether WBV is a useful alternative treatment to enhance postural control post-stroke.

Sensation

While the WBV group and exercise on music group were shown to have comparable improvements in somatosensory threshold by van Nes et al. [37], we cannot conclude the WBV is in fact effective because the improvement can be due to the conventional rehabilitation program that both groups received. Additionally, factors that are common in both groups, such as maturation effects, may also account for the observed improvement.

Activity and participation

Functional mobility

Of the two studies that compared WBV with other exercise approaches,[37,40] Merkert et al.[40], but not van Nes et al.[37], demonstrated better outcomes in the WBV group.[40] As aforementioned, the WBV group in the former study received more treatment time than the comparison group, which may partially explain the better outcomes.

Activities of daily living

Barthel Index was measured in two studies, which compared WBV with other forms of exercise, but the results were conflicting.[37,40] The additional treatment time from WBV training in Merkert et al.[40] may contribute to the signficant results, as opposed to van Nes et al., in which the total treatment time for both groups was even. Due to the limited number of studies and conflicting findings, no conclusion can be driven regarding the therapeutic effects of WBV on this domain of function.

Relationship between treatment effect and characteristics of participants

Although the participants with subacute stroke tended to be more impaired than those in the chronic stage of recovery, their response to WBV did not seem to systematically differ. Of the two studies that investigated the effects of a single WBV session, both Tihanyi et al.[38] (subacute trial) and Chan et al.[44] (chronic trial) reported mixed results, with positive findings on some outcomes, but not others. With regards to the effects of multiple WBV sessions, since all studies that involved comparison 1 employed individuals after chronic stroke and the disability level was similar across studies, meaningful comparison can only be made among four studies (three subacute stroke trials[37,39,40] and 1chronic stroke trial[46]) that involved comparison 2. The chronic stroke trial by Tankisheva et al.[46] reported mixed results, just as Tihanyi et al.[39] and Merkert et

al.[40] (both were subacute trials). Van Nes et al. (subacute trial) was the only study that reported no significant results across all outcomes but the characteristics of their participants were not distinctly different from the other two subacute trials. Taken together, no specific trend can be identified in terms of the relationship between the WBV treatment effect and characteristics of the participants.

Limitations of the Studies Reviewed

Only two of the nine studies were regarded as level 1 evidence. With few exceptions,[37,41,42] physiological justifications of the WBV protocol used were not provided. Additionally, four studies had very small sample sizes (≤20 subjects), which lowered the statistical power and representativeness of sample.[38-40,46] The total treatment time differed for the various treatment arms in a number of studies,[39,40,46] which posed a threat to internal validity.

Limitations of the Systematic Review

It is difficult to delineate the effects of each WBV parameter (WBV type, frequency, amplitude, peak acceleration, treatment duration and frequency) on treatment outcomes, as differences exist in multiple parameters across studies. Perhaps the most important limitation of this review is that we could not draw any conclusion as to whether WBV is an effective treatment for a specific deficit induced by stroke. However, it is difficult to identify a particular main problem in a given individual with stroke, as stroke often affects multiple domains of function which are highly inter-correlated. Apparently, none of studies reviewed here had considered this issue and described the participants as having a particular main deficit. In fact, there is considerable heterogeneity of participant characteristics within the individual studies, making it more difficult to detect significant effects.

Future research directions

This review has revealed many gaps of knowledge in the field. First, some fundamental questions have to be addressed before a large-scale clinical trial is conducted. For example, how the EMG responses of different muscle groups vary with different exercises during exposure to various WBV frequencies and amplitudes in people with stroke is largely unknown. Whether patients with different levels and types of motor impairment demonstrate different EMG response during the application of the same WBV protocol is also uncertain. The transmissibility of WBV signals to different parts of the body and how it varies with vibration frequency and amplitude should be studied as well. Such information would be useful in guiding the design of WBV exercise protocols for efficacy testing in future clinical trials. Second, to truly determine whether WBV has therapeutic value, RCTs with large sample sizes are required to compare the effects of different WBV protocols on various outcomes. Measures with good psychometric properties should be used. Measures of participation should also be incorporated in future clinical trials. More homogenous groups of patients with specific impairments should be used, in order to improve internal validity and allow for drawing conclusion that speaks to a particular problem or deficit. Once the therapeutic value of WBV is established, efforts should be made to decipher the mechanisms related to WBV therapy. For example, the improvement in muscle strength (if any) may be related to peripheral (e.g., change in

contractile properties of muscle) or/and central mechanisms (change in excitability of cortical motoneurons), which may be worth investigating.

Conclusion

No solid evidence was found confirming the beneficial effects of WBV after a single treatment session or an intervention period of 3-12 weeks among people with stroke, compared with either no WBV under the same exercise condition, or other types of physical activities. This is partially due to the limited number of studies investigating the topic of WBV in stroke, lack of identification of the main impairment of the study participants, poor methodological quality and heterogeneity of samples used. In summary, based on the evidence available in the literature, clinical use of WBV in stroke rehabilitation is not supported.

ACKNOWLEDGMENT

L.-R. Liao was supported by the General Research Fund provided by the Research Grants Council (no. PolyU 5245/11E). F. M. H. Lam was supported by a full-time PhD studentship provided by the Hong Kong Polytechnic University. All authors provided concept/idea/research design and data analysis. Mr. Liao provided writing. Mr. Liao, Ms. Huang, Mr. Lam provided data collection and analysis. Dr. Pang provided project management and consultation (including review of manuscript before submission).

References

1 Eklund G, Hagbarth KE. Normal variability of tonic vibration reflexes in man. *Exp Neurol*. 1966;16:80–92.

2 Issurin VB, Liebermann DG, Tenenbaum G. Effect of vibratory stimulation training on maximal force and flexibility. *J Sports Sci.* 1994;12:561–566.

3 Issurin VB, Tenenbaum G. Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *J Sports Sci.* 1999;17:177–182.

4 Martínez F, Rubio JA., Ramos DJ, Esteban P, Mendizábal S, Jiménez F. Effects of 6-week whole body vibration training on the reflex response of the ankle muscles: a randomized controlled trial. *Int J Sports Phys Ther*. 2013;8:15–24.

5 Bosco C, Cardinale M, Tsarpela O. Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *Eur J Appl Physiol Occup Physiol*. 1999;79:306–311.

6 Torvinen S, Kannu P, Sievänen H, et al. Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. *Clin Physiol Funct Imaging*. 2002;22:145–152.

7 Lau RWK, Liao LR, Yu F, Teo T, Chung RC, Pang MY. The effects of whole body vibration therapy on bone mineral density and leg muscle strength in older adults: a systematic review and meta-analysis. *Clin Rehabil*. 2011;25:975–988.

8 Jordan MJ, Norris SR, Smith DJ, Herzog W. Vibration training: an overview of the area, training consequences, and future considerations. *J Strength Cond Res*. 2005;19:459–466.

9 Luo J, McNamara B, Moran K. The use of vibration training to enhance muscle strength and power. *Sports Med.* 2005;35:23–41.

10 Cardinale M, Leiper J, Erskine J, Milroy M, Bell S. The acute effects of different whole body vibration amplitudes on the endocrine system of young healthy men: a preliminary study. *Clin Physiol Funct Imaging.* 2006;26:380–384.

11 Rehn B, Lidström J, Skoglund J, Lindström B. Effects on leg muscular performance from whole-body vibration exercise: a systematic review. *Scand J Med Sci Sports*. 2007;17:2–11.

12 Hazell TJ, Kenno KA, Jakobi JM. Evaluation of muscle activity for loaded and unloaded dynamic squats during vertical whole-body vibration. *J Strength Cond Res.* 2010; 24:1860–1865.

13 Pollock RD, Woledge RC, Mills KR, Martin FC, Newham DJ. Muscle activity and acceleration during whole body vibration: effect of frequency and amplitude. *Clin Biomech.* 2010;25:840–846.

14 Cardinale M, Lim J. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *J Strength Cond Res.* 2003;17:621–624.

15 Ritzmann R, Kramer A, Gruber M, Gollhofer A, Taube W. EMG activity during whole body vibration: motion artifacts or stretch reflexes? *Eur J Appl Physiol*. 2010; 110:143–151.

16 Kipp K, Johnson ST, Doeringer JR, Hoffman MA. Spinal reflex excitability and homosynaptic depression after a bout of whole-body vibration. *Muscle Nerve.* 2011;43:259–262.

17 Sayenko DG, Masani, K, Alizadeh-Meghrazi M, Popovic MR, Craven BC. Acute effects of whole body vibration during passive standing on soleus H-reflex in subjects with and without spinal cord injury. *Neurosci Lett.* 2010;482:66–70.

18 Mileva KN, Bowtell JL, Kossev AR. Effects of low-frequency whole-body vibration on motor-evoked potentials in healthy men. *Exp Physiol.* 2009;94:103–116.

19 Umemura Y, Ishiko T, Yamauchi T, Kurono M, Mashiko S. Five jumps per day increase bone mass and breaking force in rats. *J Bone Miner Res.* 1997; 12:1480–1485.

20 Robling AG, Duijvelaar KM, Geevers JV, Ohashi N, Turner CH. Modulation of appositional and longitudinal bone growth in the rat ulna by applied static and dynamic force. *Bone.* 2001; 29:105–113.

21 Hsieh YF, Turner CH. Effects of loading frequency on mechanically induced bone formation. *J Bone Miner Res*. 2001;16:918–924.

22 Flieger J, Karachalios T, Khaldi L, Raptou P, Lyritis G. Mechanical stimulation in the form of vibration prevents postmenopausal bone loss in ovariectomized rats. *Calcif Tissue Int.* 1998;63:510–514.

23 Rubin C, Turner AS, Bain S, Mallinckrodt C, McLeod K. Anabolism. Low mechanical signals strengthen long bones. *Nature.* 2001;412:603–604.

24 Ozcivici E, Garman R, Judex S. High-frequency oscillatory motions enhance the simulated mechanical properties of non-weight bearing trabecular bone. *J Biomech.* 2007;40:3404–3411.

25 Belavý DL, BellerG, Armbrecht G, et al. Evidence for an additional effect of whole-body vibration above resistive exercise alone in preventing bone loss during prolonged bed rest. *Osteoporos Int.* 2011;22:1581–1591.

26 Lam FMH, Lau RWK, Chung RCK, Pang MY. The effect of whole body vibration on balance, mobility and falls in older adults: a systematic review and meta-analysis. *Maturitas.* 2012; 72:206–213.

27 Rogan S, Hilfiker R, Herren K, Radlinger L, de Bruin ED. Effects of whole-body vibration on postural control in elderly: a systematic review and meta-analysis. *BMC Geriatr.* 2011;11:72.

28 Slatkovska L, Alibhai SMH, Beyene J, Cheung AM. Effect of whole-body vibration on BMD: a systematic review and meta-analysis. *Osteoporosis Int.* 2010;21:1969–1980.

29 Bruyere O, Wuidart M-A, Di Palma E, et al. Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. *Arch Phys Med Rehabil.* 2005;86:303–307.

30 Ebersbach G, Edler D, Kaufhold O, Wissel J. Whole body vibration versus conventional physiotherapy to improve balance and gait in Parkinson’s disease. *Arch Phys Med Rehabil.* 2008;89:399–403.

31 Broekmans T, Roelants M, Alders G, Feys P, Thijs H, Eijnde BO. Exploring the effects of a 20-week whole-body vibration training programme on leg muscle performance and function in persons with multiple sclerosis. *J Rehabil Med*. 2010;42:866–872.

32 Ness LL, Field-Fote EC. Whole-body vibration improves walking function in individuals with spinal cord injury: a pilot study. *Gait Posture.* 2009;30:436–440.

33 Jette AM. Toward a common language for function, disability, and health. *Phys Ther.* 2006;86:726–734.

34 Nadeau S, Gravel D, Arsenault AB, Bourbonnais D. Plantarflexor weakness as a limiting factor of gait speed in stroke subjects and the compensating role of hip flexors. *Clin Biomech*. 1999;14:125–135.

35 World Health Organization. *International Classification of Functioning, Disability and Health: ICF*. Geneva: World Health Organization. 2001.

36 Teasell R. "Holistic" care for stroke in the context of the current health care bureaucracy and economic reality. *Top Stroke Rehabil*. 2011;18:66-69.

37 Van Nes IJW, Latour H, Schils F, Meijer R, van Kuijk A, Geurts AC. Long-term effects of 6-week whole-body vibration on balance recovery and activities of daily living in the postacute phase of stroke: a randomized, controlled trial. *Stroke*. 2006;37:2331–2335.

38 Tihanyi TK, Horváth M, Fazekas G, Hortobágyi T, Tihanyi J. One session of whole body vibration increases voluntary muscle strength transiently in patients with stroke. *Clin Rehabil*. 2007;21:782–793.

39 Tihanyi J, Di Giminiani R, Tihanyi T, Gyulai G, Trzaskoma L, Horváth M. Low resonance frequency vibration affects strength of paretic and non-paretic leg differently in patients with stroke. *Acta Physiol Hung*. 2010;97:172–182.

40 Merkert J, Butz S, Nieczaj R, Steinhagen-Thiessen E, Eckardt R. Combined whole body vibration and balance training using Vibrosphere®: improvement of trunk stability, muscle tone, and postural control in stroke patients during early geriatric rehabilitation. *Z Gerontol Geriatr*. 2011;44:256–261.

41 Lau RWK, Yip SP, Pang MYC. Whole-body vibration has no effect on neuromotor function and falls in chronic stroke. *Med Sci Sports Exerc*. 2012;44:1409–1418.

42 Pang MYC, Lau RWK, Yip SP. The effects of whole-body vibration therapy on bone turnover, muscle strength, motor function, and spasticity in chronic stroke: a randomized controlled trial. *Eur J Phys Rehabil Med*. 2013;49:439-450.

43 Brogårdh C, Flansbjer UB, Lexell J. No specific effect of whole-body vibration training in chronic stroke: a double-blind randomized controlled study. *Arch Phys Med Rehabil*. 2012;93:253–258.

44 Chan KS, Liu CW, Chen TW, Weng MC, Huang MH, Chen CH. Effects of a single session of whole body vibration on ankle plantarflexion spasticity and gait performance in patients with chronic stroke: a randomized controlled trial. *Clin Rehabil.* 2012;26:1087–1095.

45 Marín PJ, Ferrero CM, Menéndez H, Martín J, Herrero AJ. Effects of whole-body vibration on muscle architecture, muscle strength, and balance in stroke patients: a randomized controlled trial. *Am J Phys Med Rehabil*. 2013;92:881-888.

46 Tankisheva, E., Bogaerts, A., Boonen, S., Feys, H., Verschueren, S. Effects of Intensive Whole-Body Vibration Training on Muscle Strength and Balance in Adults With Chronic Stroke: A Randomized Controlled Pilot Study. *Arch Phys Med Rehabil*. 2013.

47 University of Oxford. Centre for Evidence-Based Medicine Web site. Available at: http://www.cebm.net. Accessed May 7, 2013.

48 Centre for Evidence-Based Physiotherapy. The George Institute for Global Health. Physiotherapy Evidence Database Web site. Available at: http://www.pedro.org.au. Accessed May 7, 2013.

49 Bhogal SK, Teasell RW, Foley NC, Speechley MR. The PEDro scale provides a more comprehensive measure of methodological quality than the Jadad scale in stroke rehabilitation literature. *J Clin Epidemiol.* 2005;58:668–673.

50 Pang MYC, Charlesworth SA, Lau RWK, Chung RCK. Using aerobic exercise to improve health outcomes and quality of life in stroke: evidence-based exercise prescription recommendations. *Cerebrovasc Dis.* 2013;35:7–22.

51 Hedges L, Olkin I. *Statistical methods for meta-analysis*. Orlando: Academic Press; 1985.

52 Kiiski J, Heinonen A, Järvinen TL, Kannus P, Sievänen H. Transmission of vertical whole body vibration to the human body. *J Bone Miner Res.* 2008;23:1318–1325.

53 Rubin C, Recker R, Cullen D, Ryaby J, McCabe J, McLeod K. Prevention of postmenopausal bone loss by a low-magnitude, high-frequency mechanical stimuli: a clinical trial assessing compliance, efficacy, and safety. *J Bone Miner Res*. 2004;19:343–351.

54 Verschueren SMP, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. *J Bone Miner Res*. 2004;19:352–359.

55 Von Stengel S, Kemmler W, Engelke K, Kalender WA. Effect of whole-body vibration on neuromuscular performance and body composition for females 65 years and older: a randomized-controlled trial. *Scand J Med Sci Sports.* 2012;22:119–127.

56 Turner S, Torode M, Climstein M, et al. A randomized controlled trial of whole body vibration exposure on markers of bone turnover in postmenopausal women. *J Osteoporos*. 2011; 2011:1-10.

57 Pang MYC, Ashe MC, Eng JJ. Compromised bone strength index in the hemiparetic distal tibia among chronic stroke patients: the role of cardiovascular function, muscle atrophy, mobility, and spasticity. *Osteoporos Int*. 2010;21:997-1007.

58 Levendoglu F, Ugurlu H, Gurbilek M, Akkurt E, Karagozolu E. Increased bone resorption in the proximal femur in patients with hemiplegia. *Am J Phys Med Rehabil*. 2004;83:835-841.

59 Marin, P.J. and Rhea, M.R. Effects of vibration training on muscle power: a meta-analysis. *J Strength Cond Res*. 2010;24:871-878.

60 Kipp K, Johnson ST, Doeringer JR, Hoffman MA. Spinal reflex excitability and homosynaptic depression after a bout of whole-body vibration. *Muscle Nerve.* 2011; 43:259–262.

61 Sayenko DG, Masani, K, Alizadeh-Meghrazi M, Popovic MR, Craven BC. Acute effects of whole body vibration during passive standing on soleus H-reflex in subjects with and without spinal cord injury. *Neurosci Lett*. 2010;482:66–70.

62 Ansari NN, Naghdi S, Arab TK, Jalaie S. The interrater and intrarater reliability of the Modified Ashworth Scale in the assessment of muscle spasticity: limb and muscle group effect. *NeuroRehabilitation*. 2008;23:231-237.

63 Fleuren JF, Voerman GE, Erren-Wolters CV, Snoek GJ, Rietman JS, Hermens HJ, Nene AV. Stop using the Ashworth Scale for the assessment of spasticity. *J Neurol Neurosurg Psychiatry*. 2010;81:46-52.

64 Singh P, Joshua AM, Ganeshan S, Suresh S. Intra-rater reliability of the modified Tardieu scale to quantify spasticity in elbow flexors and ankle plantar flexors in adult stroke subjects. *Ann Indian Acad Neurol*. 2011;14:23-26.

65 Tsang CSL, Liao LR, Chung RCK, Pang MYC. Psychometric properties of the mini-balance evaluation systems test (Mini-Bestest) in community-dwelling individuals with chronic stroke. *Phys Ther*. 2013;93:1102-1115.

Table 1. Rating of the PEDro scale and level of evidence

Criterion	**Study**								
	Comparison 1 (5 studies)[a]					**Comparison 2 (4 studies)[b]**			
	Tihanyi et al., 2007[38]	**Lau et al., 2012[41] & Pang et al., 2013[42]**	**Brogardh et al., 2012[43]**	**Chan et al., 2012[44]**	**Marin et al., 2013[45]**	**van Nes et al., 2006[37]**	**Tihanyi et al., 2010[39]**	**Merkert et al., 2011[40]**	**Tankisheva et al., 2013[46]**
PEDro Scale									
Eligibility Criteria	Yes	Yes	Yes	Yes	**No**	Yes	Yes	Yes	**Yes**
Random Allocation	1	1	1	1	1	1	1	1	**1**
Concealed Allocation	1	1	1	1	1	1	0	0	**1**
Baseline Comparability	1	1	0	1	1	1	1	1	**1**
Blind Subjects	0	0	1	1	0	0	0	0	**0**
Blind Therapists	0	0	1	0	0	0	0	0	**0**
Blind Assessors	0	1	1	1	1	1	0	0	**1**
Adequate follow-up	1	1	1	1	1	1	0	0	**1**
Intention-to-treat analysis	0	1	1	0	1	1	1	0	**1**
Between group comparisons	1	1	1	1	1	1	1	1	**1**
Point estimates and variability	1	1	1	1	1	1	1	1	**1**
TOTAL PEDro score	**6**	**8**	**9**	**8**	**8**	**8**	**5**	**4**	**8**
Sample size ≥50	**No**	**Yes**	**No**	**No**	**No**	**Yes**	**No**	**Yes**	**No**
Level of evidence	**2**	**1**	**2**	**2**	**2**	**1**	**2**	**2**	**2**

[a]**Comparison** 1: exercise under the same condition as the WBV group, but without WBV or with sham vibration.
[b]**Comparison** 2: other forms of exercise/physical activity

Table 2. Subjects characteristics of studies

Study	Subject characteristics [a]						Inclusion criteria	Exclusion criteria	Severity of impairments at baseline[a]	
	Sample size	Age (y)	Sex	Post stroke duration	Paretic side, R/L	Type of stroke, infarct-ion/ Hemorr -hage			Measure	Values
Studies that assessed the effects of a single WBV session (comparison 1)										
Tihan-yi et al., 2007[38]	Subacute stroke (n=16) WBV, n=8 CON, n=8	58.2± 9.4	F=6 M=10	27.2±10.4 (days)	10/6	11/5	• First-time stroke • 14 to 50 days after stroke onset • FIM score at admission of 60–110	• Unstable cardiac conditions • Peripheral arterial disease • Severe dementia, • Unable to follow simple commands • Painful orthopedic conditions involving the pelvis and lower limbs	BI (0-100)[b] FIM (18-126)[b]	46(25-85) 84(63-110)
Chan et al., 2012[44]	Chronic stroke (n=30) WBV, n=15 CON, n=15	55.5± 9.4	F=9 M=21	34.7±32.6 (months)	11/19	15/15	• First stroke • Stroke onset >6 months • Ankle MAS ≥2 • Able to ambulate with or without assistive devices for at least 100 m • MMSE ≥24 • No joint contractures • Able to complete functional walking tests.	• Gallbladder or kidney stones • Recent leg fractures Internal fixation implants • Cardiac pacemaker, Intractable hypertension • Recent thromboembolism • Recent infectious diseases	Ambulatory device use, n Regular cane Quad cane MAS (0-5)	 6 8 2.4±0.5

Studies that assessed the effects of multiple WBV sessions (comparison 1)

Lau et al., 2012[41] and Pang et al., 2013[42]	Chronic stroke (n=82) WBV, n=41 CON, n=41	57.4± 11.2	F=24 M=58	5.0±3.9 (years)	48/34	41/41	• Hemispheric stroke • Stroke onset >6 months previously • Medically stable • AMT≥6 • Able to stand independently with or without aids for at least 1.5 minute • Age≥18 years	• Other neurological conditions • Serious musculoskeletal conditions • Pain that affected the performance of physical activities • Metal implants or recent fractures in the lower extremity • Vestibular disorders • Peripheral vascular disease • Other serious illnesses • Pregnancy	Walking aids indoors (none/cane/quad cane) CMSA leg score (out of 7) [b] CMSA foot score (out of 7) [b] No. subject with at least one fall in past 3 months FAC (1-5) [b] BBS Isometric knee concentric extension peak power (W/kg) Paretic leg Non-paretic leg	65/8/9 4 (3-6) 3 (1-6) 4 5 (3-5) 50.8±6.7 0.65±0.33 1.18±0.45
Brogardh et al., 2012[43]	Chronic stroke (n=31) WBV, n=16 CON, n=15	62.6± 7.3	F=6 M=25	35.3±30.6 (months)	15/16	27/4	• Able to walk ≥300m • ≥10% self-perceived muscle weakness in the knee extensors or knee flexors in the paretic leg • Not engaging in any heavy resistance or high-intensity training	• Epilepsy • Cardiac disease • Cardiac pace-maker • Osteoarthritis in the lower limbs • Knee or hip joint replacement • Thrombosis in the lower limbs in the past 6 months	FIM (18-126) BBS (0-56) Isometric knee extension (Nm) Paretic leg Non-paretic leg	83.3±3.2 51.2±2.3 98.2±33.7 144.8±36.2
Marin et al.,2013[45]	Chronic stroke (n=20) WBV, n=11 CON, n=9	63.2± 9.4	F=9 M=11	4.3±2.5	10/10	17/3	• Stroke onset ≥ 6 months • NIHSS score > 1 and < 20	• Dementia or severe cognitive impairment • Knee joint pain • Unable to remain standing without external support for ≥30 seconds.	NIHSS (0-42) BBS (0-56)	1.3±0.5 46.1±9.1

Studies that assessed the effects of multiple WBV sessions (comparison 2)

van Nes et al., 2006[37]	Subacute stroke (n=53) WBV, n=27 CON, n=26	61.1± 10.1	F=23 M=30	36.6±9.7 (days)	28/25	38/15	• Stroke onset less than 6 weeks • Moderate or severe balance impairments BBS<40)	• Non-stroke related sensory or motor impairments • Medication that could interfere with postural control • Unable to follow simple verbal instructions Pregnancy • Recent fractures • Gallbladder or kidney stones • Malignancies • Cardiac pacemaker	MI (0-100) MAS (0-5)[b] Knee flexion Knee extension Ankle DF Ankle PF BBS (0-56) BI (0-20) Trunk control Test (0-100) RMI (0-15) FAC (0-5)[b]	49.0±28.6 0(0-3) 0(0-4) 1(0-4) 0(0-2) 23.8±16.8 10.1±3.4 72.3±25.0 5.3±3.1 1(0-4)
Tihanyi et al., 2010[39]	Subacute stroke (n=20) WBV, n=10 CON, n=10	58.6± 6.3	F=8 M=12	26.8±9.3 (days)	10/10	12/8	• Be able to stand for ≥2 minutes • Able to perform the outcome assessments	NR	BI (0-100) Maximal isometric knee extension torque (Nm) Paretic Non-paretic	48.0±14.9 39.5±27.6 89.5±33.9
Merkert et al., 2011[40]	Subacute stroke (n=66) WBV, n=33 CON, n=33	74.5± 8.5	F=44 M=22	54.2±149. 9(days)	NR	NR	• Decreased stability of the trunk or lower limb • Aged ≥60 years	• Thrombosis • Acute illness or infections • Operations of the spine or lower extremities within the past 6 months • Implanted pacemakers or defibrillators • Severe cognitive impairment • Body weight >150 kg	BI (0-100) Tinetti Gait Test (0-12) TUG Functional test of the lower back (0-20) BBS (0-56)	42.0±21.1 7.7±3.0 30.0±10.6 13.8±7.3 20.5±16.4
Tankisheva et al., 2013[46]	Chronic stroke (n=15) WBV, n=7 CON, n=8	61.6 ± 9.2	F=5 M=10	6.4±6.4	7/8	11/4	• Aged 40- 75 years • First-ever stroke • Stroke onset >6 months • Medically stable • Able to stand independently with or without aids for at least 20 minutes • Ability to perform the	• Acute thrombotic diseases • Severe heart and vascular diseases • Cardiac pacemaker • Acute hernia • Diabetes • Tumors • Other neurologic disorders Rheumatoid arthritis Arthrosis • Osteoarthritis	Isometric knee extension strength (Nm) Paretic leg Nonparetic leg BI (0-100) FAC (1-6)[b] Brunnstrom-Fugl-Meyer test Ashworth Scale	 96.4±19.6 135.7±16.0 90.4±10.2 5(3-5) 22.9±5.3 4.5 (0-14)

experimental treatment independently	• Diskopathy • Spondylosis	composite score (0-24) [b]	
		SOT	
		C1	92.7±2.4
		C2	89.9±3.0
		C3	89.4±4.1
		C4	73.8±6.5
		C5	41.8±28.9
		C6	51.3±19.5

AMT= Abbreviated Mental Test; C=Condition; CON=control group; BBS=Berg Balance Scale; BI=Barthel Index; CMSA=Chedoke McMaster Stroke Assessment; F=female; FAC=Functional Ambulation Category; FIM =Functional Independence Measure; L/R =left/right; M=male; MAS=Modified Ashworth Scale; MI=Motricity Index; MMSE=Mini-mental State Examination; NIHSS=National Institutes of Health Stroke Scale; NR=not reported; RCT=randomized controlled trial; RMI=Rivermead Mobility Index; s=second; SOT=Sensory Organization Test; TUG=Timed-Up-and-Go test; WBV=whole body vibration group; y=years.

[a] Mean±SD presented unless indicated otherwise.

[b] Median(Range).

Table 3. Training protocols for WBV group and comparison group

Study	Protocol for WBV group [b]								Protocol for comparison group
	WBV treatment						Additional treatment	Super-vision	
	Frequency of sessions × duration of program	Number of vibration bouts × duration per bout	Rest between bouts	Frequency (Hz) and amplitude (mm) and peak acceleration (g) of vibration signals	WBV type	Posture			
Studies that assessed the effects of a single WBV session (comparison 1)									
Tihanyi et al., 2007[38]	Single session	6 bouts× 1 min	120s	20Hz, 2.5mm, 4.0g	Synchronous Vertical	Standing on the platform with slightly knees flexion at 40 degrees and shifted their body mass to the paretic leg	None	NR	Same exercise but without vibration
Chan et al., 2012[44]	Single session	2 bouts× 10 min	60s	12 Hz, 4mm, 2.3g	Synchronous Vertical	Positioned on the platform in a semi-squatting position with buttock support and were kept in an upright position with even weight distribution on both feet	None	NR	Followed the same procedures, but the vibration machine was not turned on.
Studies that assessed the effects of multiple WBV sessions (comparison 1)									
Lau et al., 2012[41] & Pang et al., 2013[42]	3/week × 8 week	1.5min×6 bouts to 2.5min×6 bouts	3min to 4.5min	20-30Hz 0.44-0.60mm1.0-1.6g	Synchronous Vertical	Side to side weight shift; Semi squat; Forward and backward ; weight shift; Forward lunge; Standing on one leg; Deep squat	15 minutes of warm-up exercises (general mobilization and stretching) in a sitting position	Therapist	Performed the same exercises on the same WBV platform as the WBV group but without vibration

Brogardh et al., 2012[43]	2/week × 6 week	40s×4 bouts to 60s×12 bouts	60s	25Hz, 3.75mm, 9.2g	Synchronous Vertical	Standing barefoot on the platforms in a static position with the knees flexed 45° -60° and with handhold support, if needed	None	Physical therapist	Same exercises on a vibration platform with an amplitude of 0.20mm and frequency 25Hz
Marin et al.,2013[45]	1/week from week 1 to 7 and 2/week from week 8 to 12	1-2 session: 4 bouts×30s; 3-4 session: 5 bouts×30s; 5-6 session: 5 bouts×50s; 7-8 session: 5 bouts×60s; 9-12 session: 6 bouts×60s; 13-17 session: 7 bouts×60s	60s	5-21Hz 2-3mm 0.2-5.3g	Side-alternating Vertical	Standing on a vibration platform with a knee flexion of 30 degrees	Ten 2-hour rehabilitation sessions per month	Therapist	Performed the same exercises as that of the experimental group but was not exposed to vibration, and ten 2-hour rehabilitation sessions per month

Studies that assessed the effects of multiple WBV sessions (comparison 2)

van Nes et al., 2006[37]	5/week × 6 weeks	4 bouts × 45s	60s	30Hz, 3mm, 10.9g	Side-alternating Vertical	Standing on the platform with knees slightly flexed	None	Physical therapist	Exercise therapy on music: regular exercises for the trunk, arm, and leg muscles
Tihanyi et al., 2010[39]	3/week × 4 week	6 bouts × 1 min	60s	20Hz, 2.5mm, 8.05g	Synchronous Vertical	Knee flexed at 80°, then shifting body weight to each leg while flexing and extending the knee with a range of motion of 10°-15°	Daily conventional physiotherapy	NR	Daily conventional physiotherapy

Merkert et al., 2011[40]	5/week × 3 week	2 bouts × 90s	15s-90s	20-45Hz Amplitude not reported	Vibro-sphere®	Bridging in supine, sitting on Vibrosphere®, with trunk extension and flexion, and supported and unsupported standing	Conventional comprehen-sive geriatric rehabilitation	NR	Conventional comprehensive geriatric rehabilitation
Tankisheva et al., 2013[46]	3/week × 6 week	1-12 session: 5 bouts×30s; 13-18 session: 17 bouts×60s	NR	35Hz, 1.7mm,8.4g 40Hz, 2.5mm,16.1g	Synchronous Vertical	Standing on their toes, knee flexion of 50° to 60° (high squat), knee flexion of 90° (deep squat), wide-stance squat, and 1-legged squat	None	Trainer	The participants of the CON group were not involved in any additional training program and were asked not to change their lifestyle.

[a] Mean±SD presented unless indicated otherwise.
[b]s=second; NR=not reported; WBV=whole body vibration.
CON=control group; F=female; M=male; RCT=randomized controlled trial; WBV=whole body vibration group.

Table 4. Summary of immediate effects of a single session of WBV on body functions and structures, and activity in people with stroke

Study (com-parator 1)	Aim	Measurement schedule	Outcome measures[a]		Conclusion
			No significant results	Significant results	
Tihanyi et al. 2007[38d]	"To determine the transient effect of WBV on maximal voluntary force and agonist and antagonist muscle activation" in people with stroke.	Pre-test, post-test	• Mechanical work during eccentric contraction	• ↑Maximum isometric knee extension torque (SES =0.50)[b] • ↑Maximum eccentric knee extension torque (SES =0.46) • ↑Rate of torque development (SES = 0.08) • ↑Maximal voluntary eccentric torque at 60 degrees of knee flexion (SES = 0.50) • ↓Co-activation quotient of BF during: • isometric knee extension (SES = 0.82) • eccentric knee extension (SES = 0.16)	"A single bout of WBV can transiently increase voluntary force and muscle activation of the quadriceps muscle affected by a stroke".
Chan et al. 2012[44]	"To investigate the effects of a single session of WBV training on ankle plantarflexion spasticity and gait performance" in people with chronic stroke.	Pre-test, post-test	• GS H-reflex in both legs • GS H_{max}/M_{max} ratio on affected side • Achilles deep tendon reflex on affected side • Cadence	• ↓GS H_{max}/M_{max} ratio on unaffected side (SES = 0.87)[b] • ↓MAS[c] • ↓VAS (perceived spasticity) (SES = 1.96) • ↓Time to complete TUG (SES =1.80) • ↑10MWT (maximal speed) (SES = 0.79) • ↑TBW % on affected side (SES = 0.87) • ↓TBW % on unaffected side (SES =0.87)	"A single session of WBV can reduce ankle plantar-flexion spasticity in chronic stroke patients, thereby potentially increasing ambulatory capacity."

[a]The results shown in this table referred to the difference between the WBV and comparison groups.
[b]The SES for this study were calculated based on the mean and SD of the change scores of the WBV and comparison groups.
[c]The SES was not reported because MAS is an ordinal variable.

[d]The EMG amplitude data of individual muscles were not included because they were not normalized, making it difficult to compare between groups.

10 MWT=10-meter walk test; ABC=activities-specific balance confidence; BBS=Berg Balance Scale; BF=biceps femoris; GS=gastrocnemius-soleus; H-reflex=Hoffmann reflex; Hmax/Mmax ratio=maximum Hoffmann reflex/maximum M response ratio; MAS=Modified Ashworth Scale; SES=standardized effect size ; TBW%=percentage of total body weight ; TUG=Timed Up & Go test; VAS=visual analogue scale; VL=vastus lateralis ; WBV=whole-body vibration ; ↑=increase; ↓=decrease

Table 5. Summary of effects of multiple WBV sessions on body functions and structures, activity and participation in people with stroke

Study	Aim	Measurement schedule	Outcome measures[a]		Conclusion
			No significant findings	**Significant findings**	
			Studies that invovled comparison 1		
Lau et al. 2012[41] &Pang et al. 2013[42]	To investigate the effects of WBV on bone turnover, neuromotor function, spasticity and reducing falls in people with chronic stroke.	Pre-test, post-test 1(week 8), post-test 2 (week 12) for all outcomes, except falls (monthly follow-up until 6 months after termination of training)	• BBS • Limit of Stability Test ○ MVL ○ EPE ○ MXE ○ DCL • 6 MWT • 10 MWT (comfortable speed) • CMSA of paretic leg and foot • Ankle spasticity (MAS) • ABC • CTx • BAP • Paretic leg isometric muscle strength ○ Knee extension ○ Knee flexion ○ Paretic and non-paretic knee peak power ○ Concentric extension ○ Concentric flexion ○ Eccentric extension ○ Eccentric flexion • Incidence of falls	↓Knee MAS (week 12)[c]	The addition of WBV to a leg exercise protocol was no more effective in improving neuromotor performance, bone turnover, paretic leg motor function and reducing the incidence of falls than leg exercises alone in chronic stroke patients who have mild to moderate motor impairments. WBV may have potential to modulate spasticity.

Brogardh et al. 2012[43]	To evaluate the effects of WBV training on muscle function, balance, gait performance and perceived participation in individuals after stroke.	Pre-test, post-test (week 6)	• MAS
			• BBS
			• Muscle strength
			  ○ Isokinetic knee extension in both legs (60°/s)
			  ○ Isokinetic knee flexion in both legs (60°/s)
			  ○ Maximum isometric knee extension in both legs
			• TUG
			• 10 MWT (comfortable and maximal speed)
			• 6MWT
			• SIS
					Six weeks of WBV training had small treatment effects on balance and gait performance in chronic stroke individuals, but was not more effective than a placebo vibrating platform.

Marin et al. 2013[45]	"To analyze the effects of WBV on lower limb muscle architecture, muscle strength, and balance in stroke patients."	Pre-test, post-test (3 months)	• Muscle thickness of RF, VL and MG in both legs • Maximal isometric knee extension strength • BBS		"WBV exercise did not augment the increase in neuromuscular performance and lower limb muscle architecture induced by isometric exercise alone in stroke patients."
			Studies that involved comparison 2		
van Nes et al. 2006[37]	"To examine whether WBV added to regular rehabilitation has beneficial effects on balance control and activities of daily living in patients with subacute stroke."	Pre-test, post-test 1 (week 6), post-test 2 (week 12)	• BBS • BI • Rivermead Mobility Index • Trunk Control Test • FAC • Motricity Index • Somatosensory threshold of affected leg		WBV was "not more effective in enhancing recovery of balance and activities of daily living than the same amount of exercise therapy on music in the post-acute phase of stroke."

Tihanyi et al. 2010[39f]	"To investigate the chronic effect of low frequency WBV on isometric and eccentric strength of knee extensors" in patients with stroke.	Pre-test, post-test (week 4)	• Rate of torque development during isometric knee extension in both legs • Mechanical work during eccentric knee extension in non-paretic leg • NP/P strength ratio during eccentric contraction in both legs • NP/P strength ratio during concentric contraction in non-paretic leg	• ↑Maximum isometric knee extension torque in paretic leg (SES = 0.46) and non-paretic leg (SES = 0.74)[d] • ↑Maximum eccentric knee extension torque in paretic leg (SES = 0.51) and non-paretic leg (SES = 0.51) • ↑Mechanical work during eccentric knee extension in paretic leg (SES = 0.16) • ↓NP/P strength ratio during concentric contraction in paretic leg[b]	WBV intervention can increase leg muscle strength after stroke and that the improvement was more pronounced in the paretic leg.
Merkert et al. 2011[40]	"To investigate the effect of the Vibrosphere®, with its combined vibration therapy and strategic balance training, on trunk stability, muscle tone, and postural control in stroke patients compared with those receiving geriatric rehabilitation alone."	Pre-test, post-test (week 3)	• BBS • Functional test of the lower back • Tinetti Gait Test	• ↓ Time to complete TUG (SES = 0.60) • ↑BI (SES = 0.61)	"Combined vibration and balance training using Vibrosphere® may be a useful addition to current rehabilitation of stroke patients."

Tankisheva et al., 2013[46]	"To explore the feasibility, safety, and possible benefits of 6 weeks of intensive WBV training in patients with chronic stroke in comparison to a control group."	Pre-test, post-test 1(week 6), post-test 2 (week 12)	• MAS • Muscle strength • Isokinetic knee extension in both legs (60°/s) • Isokinetic knee flexion in both legs (60°/s) • Isometric knee extension in nonparetic leg • Isometric knee flexion in both legs • Isokinetic knee extension in nonparetic leg (240°/s) • Isokinetic knee flexion in both legs (240°/s) • SOT • Equilibrium scores (%) in condition 1, 2, 3, 5, 6	• ↑Isometric knee extension torque in paretic leg (week 6) (SES = 1.74)[e] • ↑Isokinetic knee extension strength (240°/s) in paretic leg (week 12) (SES = 0.96) • ↑ Equilibrium scores (%) in condition 4: normal vision and sway-referenced support surface (week 6) (SES = 1.47)[e]	Six weeks of intensive WBV might "potentially be a safe and feasible way to increase some aspect of lower limb muscle strength and postural control in adults with chronic stroke."

[a]The results shown in this table referred to the difference between the WBV and comparison groups.
[b]The standardized effect size was not reported for this variable as the exact mean and standard deviation values were not presented.
[c]The SES was not reported because MAS is an ordinal variable.
[d]The SES for this study were calculated based on the mean and SD of the post-test scores of the WBV and comparison groups.
[e]The SES for this particular outcome was reported in the text by the authors.
[f] The EMG amplitude data of individual muscles were not included because they were not normalized, making it difficult to compare between groups.
6MWT=six-minute walk test; 10 MWT=10-meter walk test; ABC=activities specific balance confidence; BAP=bone-specific alkaline phosphatase; BBS=Berg Balance Scale; BI=Barthel Index; CGS= comfortable gait speed; CMSA= Chedoke-McMaster Stroke Assessment; CTx=Serum C-telopeptide of type I collagen cross-links; DCL=directional control; EPE=end point excursions; FAC=Functional Ambulation Categories; FGS=fast gait speed; MAS= Modified Ashworth Scale; MG= medial gastrocnemius; MVL= movement velocity; MXE=maximum excursion; NP/P=non-paretic to paretic; RF=rectus femoris**;** SES=standardized effect size; SIS=Stroke Impact Scale; TUG=Timed Up & Go test; VL=vastus lateralis; WBV=whole-body vibration; ↑=increase; ↓=decrease

FIGURE LEGENDS

Figure 1. Flow diagram.

Ten articles (nine studies) were included in this systematic review.

Fig. 1. Flow diagram