JRRD Volume 46, Number 4, 2009
Pages 529–542
Journal of Rehabilitation Research & Development

Whole-body vibration as potential intervention for people with low bone mineral density and osteoporosis: A review

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Abstract—Low bone mineral density (BMD) and osteoporosis are health concerns among older adults and individuals with physical, neurological, and/or mobility impairments. Detrimental changes in bone density and bone architecture occurring in these individuals may be due in part to the reduction/cessation of physical activity and the accompanying reduction of mechanical strain on bone. Changes in bone architecture predispose these individuals to fragility fractures during low-trauma events. Whole-body vibration (WBV) has been examined as an intervention for maintaining or improving bone mass among people with low BMD, because it may emulate the mechanical strains observed during normal daily activities. This article provides an overview of WBV including terminology, safety considerations, and a summary of the current literature; it is intended for rehabilitation healthcare providers considering WBV as a potential therapy for individuals with osteoporosis.

Key words: animal research, astronauts, bone mineral density, musculoskeletal, older adults, osteoporosis, physically impaired, postmenopause, spinal cord injury, whole-body vibration.

INTRODUCTION

The World Health Organization has defined osteoporosis as a skeletal disease characterized by "low bone density and microarchitectural deterioration of bone tissue with a consequent increase in bone fragility and susceptibility to fracture" [1]. Fractures can lead to increased morbidity, decreased functional mobility, and increased attendant care and healthcare costs. In the United States, 43.6 million people over the age of 50 have or are at risk for osteoporosis. By 2010, this figure is expected to rise to 52.4 million and by 2020, to 61.4 million [2]. In 2002, the incidence of fractures related to osteoporosis amounted to 1.5 million [3], at an annual direct medical care expenditure of $17.5 billion [4].

Osteoporosis is most commonly associated with older women and is in part due to hormonal changes (e.g., reductions in estrogen) and a decline in physical activity. However, men, young adults, and children can also develop osteoporosis [5]. Several subpopulations at increased risk of developing osteoporosis are astronauts [6], older adults [7], postmenopausal women [8], and individuals with physical impairments such as muscular dystrophy [9–10] or neurological impairments like spinal cord injury (SCI) [11]. For example, throughout long-duration space flights (4.0–14.4 months), astronauts experience an average decrease of bone mineral density (BMD) in weight-bearing bones of 1 percent per month [6]. Postmenopausal

Abbreviations: BMD = bone mineral density, CONSORT = Consolidated Standards of Reporting Trials, GRF = ground reaction force, RCT = randomized control trial, SCI = spinal cord injury, WBV = whole-body vibration.

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DOI:10.1682/JRRD.2008.09.0136

women experience an average 20 to 25 percent decline in lower-limb BMD over a 16-year period [8], and one in two women who are 50 years of age will develop an osteoporotic fracture in their remaining lifetime [12]. The incidence of fractures in boys with Duchenne muscular dystrophy has been shown to be as high as 44 percent [9]. Finally, 25 to 46 percent of individuals living with SCI develop fragility fractures secondary to osteoporosis, and individuals with SCI are two times more likely than controls to experience a fragility fracture [13].

Load-bearing physical activity reduces or ceases in the microgravity environment of space, with age, or with mobility or neurological impairment. A relationship between mechanical loading and bone adaptation over time has been proposed [14–15] such that reduction in the magnitude or frequency of regular load-bearing physical activity leads to excess bone resorption and a decline in BMD. Increased daily physical activity is often suggested to prevent bone loss among individuals with osteoporosis [16–18]. However, exercise may be difficult when muscles are weak or may not be feasible among persons with mobility or neurological impairments. Whole-body vibration (WBV) is an intervention that has been evaluated in animal [19–29] and human studies [30–37] as a means for emulating the mechanical strains on bone observed during normal daily activities.

The aims of this review are to (1) provide an overview of the physiological basis for the potential effects of WBV on the skeletal system, (2) review WBV-related terminology and safety considerations associated with the use of WBV as an intervention, and (3) summarize the current literature regarding the use of WBV as an intervention for preventing bone density decline or improving bone mass among astronauts, older adults, and individuals with physical or neurological impairments. The goal of this review is to provide a clinical overview of WBV for rehabilitation professionals who may be considering WBV as a potential therapy for individuals with osteoporosis. Comprehensive reviews of key biomechanical concepts and the theoretical constructs presented herein are available elsewhere [14–15,38–40].

MECHANICAL LOADING AND THE SKELETAL SYSTEM

Bone is living tissue that requires mechanical stimuli to remain healthy [14]. When a load or "stress" is applied, bone is deformed. "Strain" is a measure of this deformation and refers to the relative change in the bone dimension, such as length, width, or angulation [41]. Research exploring the bone adaptive response to mechanical loading suggests that bone cells are responsive to mechanical signals including strain magnitude and strain frequency, signals that may be important stimuli for eliciting a bone adaptive response [22,42–46]. The Daily Stress Stimulus Theory describes the intensity of bone tissue mechanical loading in terms of a daily stress stimulus [15], which considers both the magnitude and the number of cycles of loading applied to the skeleton during daily activities. The theory proposes that if the daily stress stimulus is greater than some target stimulus, a net bone gain will occur and that if the daily stress stimulus is less than some target stimulus, a net bone loss will occur. The theory also proposes that a high cycle number and low magnitude stimulation may be sufficient for maintaining bone mass [15]. Further research on the Daily Stress Stimulus Theory indicates that strain frequency may be an additional factor critical to the process of bone adaptation [40,47].

The magnitude and rate of forces applied to the skeleton are determined by the velocity of the segments in motion, number of repetitions, and muscular activity, as well as by boundary conditions such as the individual's somatotype, fitness level, performance surface, climate/weather, and shoe type [48–50]. Running and jumping induce ground reaction forces (GRFs) three to six times body weight [41]. Gravitational forces, muscle forces, and GRFs are among the loads applied to the skeleton during activities of daily living and contribute to bone modeling and remodeling. BMD accrual in young people has been associated with long-term physical activity, including running and weight training [51]. In addition, high-impact exercise has been shown to promote bone gain among well-trained female athletes [52–53].

Skeletal responses to WBV are purported to be similar to that of physical activity in that WBV activates mechanotransduction in bone and stimulates osteogenesis [43,46]. Controlled dynamic loading using varying frequencies ranging from 1 to 10 Hz produced perturbations of the intermedullary pressure in adult female rats [54]. Consequently, fluid flow increased through the extracellular spaces of the bone's canaliculi and lacunae in response to loading, and the increase in fluid flow was proportional to the loading frequency. Shear stresses on cell membranes caused by fluid flow stimulate bone cells in culture [54–55]. Extracellular fluid forces could be converted into cellular responses via several different

mechanisms: activation of membrane mechanoreceptors, focal adhesion proteins, cytoskeletal signaling, or extracellular fiber bowing [56]. Vibration stimuli have been proposed to provide mechanical loading adequate to increase fluid flow in bone and facilitate mechanotransduction [55–56].

The forces applied to bone from muscle contraction during physical activity may also create fluid flow through the extracellular spaces of the bone, thereby inducing mechanotransduction [57]. The movement of the vibration plate during WBV exposure is postulated to activate both monosynaptic and polysynaptic neural pathways adequate to generate a "tonic vibration reflex," similar to the stretch reflex. The tonic vibration reflex has been reported to be activated continuously during WBV so that the muscles continue to contract and relax cyclically until the stimulus stops [58]. Consequently, bone may respond to the applied forces generated during muscle contractions from a tonic vibration reflex.

WBV may also influence the regulation of bone remodeling indirectly via the endocrine system. WBV has been shown to acutely alter testosterone and growth hormone levels [59–60]. Serum testosterone levels have been positively associated with BMD at the ultradistal radius, lumbar spine, and hip regions in healthy men and women [61–63]. Growth hormone is known for its effects at the epiphyseal growth plate; abnormalities of skeletal growth ensue if the individual has excess or deficient growth hormone levels [41]. Growth hormone levels decrease with age but increase with exercise [41]. One study showed a 7 percent increase in testosterone and a 361 percent increase in growth hormone following an acute bout of WBV at 26 Hz and 17 *g* [59].

A second study with three intervention arms including a squat group, a squat and WBV group, and a WBV group (standing but not squatting) reported (1) an increase in serum testosterone in both the squat group and squat and WBV group, and (2) an increase in growth hormone levels in all three groups, with the greatest increases observed in the squat and WBV group [60]. Therefore, the combination of a mechanical load and WBV exposure may stimulate larger increases in growth hormone than mechanical load alone. However, no studies to date have explored whether WBV-induced changes in growth hormone or testosterone are sustained or are translated into changes in indexes of bone health.

WHOLE-BODY VIBRATION TRAINING AND TERMINOLOGY

Five factors dictate the human skeletal system's response when standing on a WBV platform: vibration direction (vertical vs oscillatory alternating), vibration frequency (in hertz), vibration magnitude measured as amplitude (displacement, in millimeters) and acceleration (in gravitational units, where 1.0 g = 9.81 m/s^2), duration of the WBV, and body position/posture on the platform.

A number of different WBV platforms are commercially available [64–68], and they provide a vibratory stimulus in one of two ways: (1) vertical displacements and (2) oscillatory alternating displacements [69]. The vertical vibration plates maintain equal vibration at all points on the plate. The plate with oscillatory motion tilts from side to side over a central fulcrum, lifting one side of the body while displacing/dropping the other side, simulating human gait. Literature comparing the effects of vibration direction on bone characteristics is limited; therefore the overall effect the direction of vibration has on bone density or whether either direction is more beneficial is unclear. One study looking at the effects of vertical versus oscillatory alternating vibrations on bone biomarkers found no significant difference between groups but reported a slightly greater increase of procollagen type 1 N-propeptide, a biomarker of bone formation, following oscillatory alternating vibrations (+20.2%) when compared with vertical vibrations (+15.2%) after 3 days/week for 12 weeks of WBV exposure [70].

A WBV platform provides several different vibration frequency and magnitude options. Resonance frequency refers to the natural vibration that every object maintains, and when a system is vibrated at its resonant frequency it will oscillate at its maximum amplitude and acceleration [71]. The internal organs of the body vibrate in a frequency range of ~5 to ~20 Hz [72], and therefore the body will attempt to damp these frequencies of vibration via bone, cartilage, synovial fluids, soft tissue, and muscular activity as a protective mechanism [73]. Consequently, vibration frequencies at or near ~5 to ~20 Hz may not be anabolic or may be harmful [71,74–75]. In addition, muscle damage can occur if frequencies exceed 70 Hz [76]. Therefore, using frequencies ≥20 and ≤70 Hz for WBV training is recommended as a safety measure. Studies that demonstrate improvements in muscle strength and size using WBV have employed frequencies of 25 to 45 Hz [59,77–85].

The magnitude of a vibration stimulus is a combination of amplitude and acceleration; however, acceleration alone is often used interchangeably with the term "magnitude." Amplitude describes how much motion exists in each direction (in millimeters) while acceleration describes how quickly the motion exists in each direction (in gravitational units) [69]. As mentioned, gravitational forces obtained from activities of daily living contribute to bone modeling and remodeling; in parallel, applied forces from a WBV platform could provide these same gravitational forces. For a given peak-to-peak displacement, an increase in frequency will increase acceleration (and therefore the cyclic forces applied to the subject) according to the following **Equation**:

$$A = 2 \times \pi^2 \times F^2 \times D \ ,$$

where A = acceleration (in millimeters per seconds squared), F = vibration frequency (in hertz), and D = peak-to-peak displacement (in millimeters) (**Figure**). Thus, while a 2 mm displacement magnitude at 20 Hz will produce only 1.6 *g* peak acceleration, a 2 mm displacement magnitude at 60 Hz will produce 14.5 *g* peak acceleration.

Numerous animal studies reporting positive effects of WBV on bone characteristics have employed magnitudes of <1 *g* [19–21,24–25], and studies among young human participants showing improvements in bone characteristics following WBV have employed magnitudes of <1 *g* [30–32]. In contrast, magnitudes of <1 *g* utilized in studies among older adults showed no positive changes in bone characteristics [33,35], but higher magnitudes of 1 to 5 *g* did show positive changes [36–37].

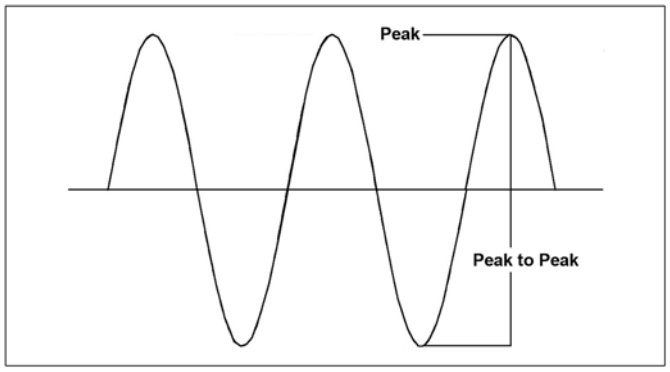

Figure.
Amplitude (peak-to-peak displacement) from vertical whole-body vibration platform.

Duration of WBV stimuli is defined as the length of time a participant is exposed to a WBV stimulus in one session. Recommendations for duration of WBV exposure in a single session vary from ~2 to 20 minutes depending on the therapeutic objectives [64,86]. Repeated cycles of short vibration periods followed by quiescent periods are most likely to stimulate bone formation [41]; intermittent vibration is more beneficial than continuous vibration for promoting musculoskeletal adaptations [87].

The final factor influencing the response of the body to WBV stimuli is joint angle, because it affects the transmissibility of vibration through the body. An erect posture will enhance the transmissibility through the hip, spine, and possibly head, whereas a relaxed stance (i.e., flexed knees) will decrease transmissibility [74].

As a result of the large number of vibration factor interactions, standardized WBV guidelines for the maintenance or improvement of BMD among older adults or those with physical or neurological impairments have not yet been established. For individuals who cannot weight bear or stand independently, WBV can be modified or used in conjunction with other rehabilitation apparatus, such as a passive standing frame or a body-weight-supported harness.

WHOLE-BODY VIBRATION SAFETY CONSIDERATIONS

Given that older adults and individuals with physical or neurological impairments are at a higher risk of experiencing adverse effects from WBV stimuli, the safety of these individuals must be ensured. The contraindications for both vertical and oscillatory alternating WBV are similar, and manufacturers that have equipment registered with the Food and Drug Administration have guidelines stating that individuals who have one of the following conditions should not partake in WBV training: kidney or bladder stones, arrhythmia, pregnancy, epilepsy, seizures, cancer, a pacemaker, untreated orthostatic hypotension, recent implants (joint/corneal/cochlear, etc.), recent surgery, recently placed intrauterine devices or pins, acute thrombosis or hernia, acute rheumatoid arthritis, serious cardiovascular disease, severe diabetes, or migraines [64–66].

Most of the documented negative effects of WBV have been observed in the workplace through exposure to large vibration loads or chronic exposure to vibration.

These negative effects include damage to biological structures including peripheral nerves, blood vessels, joints, and perceptual function [88–89]. The frequency and magnitude of workplace WBV are very different than those used for therapeutic WBV. Although published research on vertical WBV is more comprehensive than that on oscillatory alternating WBV, very little is documented or published regarding adverse events or serious adverse events resulting from either type of WBV exposure. Among published literature, several studies utilizing a low magnitude, high frequency WBV stimulus among populations with physical or neurological impairments have reported no adverse reactions [33,35,90–96]. In the field of WBV, whether adverse events in fact do not occur or are underreported or not reported is unknown. Future studies of WBV should systematically record and report data on side effects and adverse events. One clinical trial conducted at Lyndhurst Centre, Toronto Rehabilitation Institute, on the effects of passive standing and WBV among individuals with SCI reported several adverse events including pain, pressure sores on the feet, autonomic dysreflexia, and dizziness, which were largely attributed to the passive standing portion of the intervention. Two serious adverse events were reported including a fall resulting in lower-limb fracture (unrelated to intervention) and one case of deep vein thrombosis (unknown whether related or unrelated to intervention).[*] Researchers at Lyndhurst Centre caution that WBV may elicit inner ear troubles, dizziness, headache, lower-limb spasticity, fracture (especially among those with severe osteoporosis), and/or hardware loosening (plates or screws as a result of surgery).*

ANIMAL STUDIES OF WHOLE-BODY VIBRATION

Animal studies looking at the therapeutic effects of a WBV stimulus on bone utilize relatively low vibration magnitudes, and in some studies, the magnitudes of acceleration were lower than those typical of walking (0.3 *g*) [19–21]. As previously mentioned, high vibration frequency (~25–45 Hz) is suggested to produce anabolic responses in the musculoskeletal system. WBV studies in animals indicate that bone cells may be responsive to a low magnitude, high frequency WBV stimulus [19–27]. Compared with controls, one study reported a 10.6 percent increase in trabecular bone mineral content of sheep tibia after a low magnitude (0.3 *g*), high frequency (20–50 Hz) WBV stimulus for 20 minutes/day for 1 year [21]. Similarly, 6.5 and 34.2 percent increases in total BMD and trabecular BMD, respectively, of the tibia in adult female sheep were observed following a low magnitude (0.3 *g*), high frequency (30 Hz) WBV stimulus for 20 minutes/day for 1 year [19]. Ovariectomized rats exposed to WBV had increased BMD relative to controls [28]. Further research has reported augmented BMD following WBV in sheep animal models [20,22].

Improved trabecular bone stiffness, strength, and number have also been reported following a low magnitude, high frequency WBV stimulus [19,21–22,27]. The observed changes in bone quantity and quality may be due to increases in bone formation. Increases of 88 and 66 percent in trabecular bone formation rate were demonstrated following a 0.3 and 0.6 *g* magnitude, high frequency (45 Hz) WBV stimulus, respectively [24]. In addition, when compared with controls, adult female rats showed a 97 percent increase in bone formation rate following a low magnitude (0.25 *g*), high frequency (90 Hz) WBV intervention for 10 minutes/day for 28 days [25]. Other studies support these findings, reporting an increase in bone formation rate [23] and a doubling of bone formation rate [22] following low magnitude, high frequency WBV. Following disuse, bone formation rates can decrease by 92 percent [25]; WBV has been shown to prevent bone loss in a model of disuse osteoporosis [22] and to normalize bone formation rates [25]. Two studies utilizing an ovariectomized rat model reported reduced bone loss following WBV exposure (2 *g*, 50 Hz) for 30 minutes/day for 12 weeks [28] and an inhibited bone resorption paired with an increased bone formation rate following WBV exposure (3*g*, 45 Hz) for 30 minutes/day for 90 days [29]. In summary, research in animals provides evidence that WBV may alter bone remodeling and improve bone density and bone structure.

WHOLE-BODY VIBRATION TRAINING IN ASTRONAUTS

Bone loss and muscle atrophy experienced among astronauts in the microgravity environment of space can be

[*]Craven BC. Effectiveness of vibration and standing versus standing alone for the treatment of osteoporosis for people with spinal cord injury. http://clinicaltrials.gov/, NCT00150683; 2001.

compared in varying degrees to that which is experienced by individuals confined to bed rest or individuals with motor complete SCI. Bone loss among astronauts is perhaps the best-known consequence of space flight; it is a major concern, as bone loss is accelerated by a factor of 10 compared with Earth [25]. The extent to which astronauts experience bone loss depends on time spent in space, individual adaptation to weightlessness, and efficacy of countermeasures [97]. Augmenting existing countermeasures with mechanical stimulation such as WBV has shown some success in the prevention of bone loss over the past decade [98–99]. For example, BMD was maintained during a long-term space flight (5 months) following a short-term, high-impact WBV stimuli, while BMD was reduced by up to 7 percent among the astronauts who received no WBV stimulus [98].

WHOLE-BODY VIBRATION STUDIES AMONG YOUNG PERSONS

WBV has been shown to be anabolic to trabecular and cortical bone among young adults [30] and children [31–32] with low BMD or physical impairments (**Table 1**). Following a 12-month WBV intervention (0.3 *g*, 30 Hz, 10 minutes/day), a 2.1 percent increase in trabecular BMD of the lumbar vertebrae and a 3.4 percent increase in cortical BMD of the femoral midshaft were reported among young women aged 15 to 20 years with low BMD and a history of at least one prior skeletal fracture [30]. Note that this was not a randomized design; participants were assigned to each group based on residential address. Studies conducted among children with physical impairments implemented a WBV intervention as a surrogate for suppressed muscular activity by inducing muscular contractions and, consequently, increasing BMD. Following a WBV stimulus (0.3 *g*, 30 Hz) for 3 days/week for 8 weeks in a pilot study, a 6.2 percent increase in trabecular BMD and a 2.1 percent increase in cortical BMD were found among children with diabetes mellitus or idiopathic osteoporosis [31]. In addition, a randomized control trial (RCT) study conducted among children with cerebral palsy or muscular dystrophy reported a 6.3 percent increase in tibial volumetric trabecular BMD in the WBV group (0.3 *g*, 90 Hz, 10 minutes/day, 5 days/week for 6 months) compared with a 11.9 percent decrease in the control group, resulting in a net benefit of treatment of 17.7 percent [32]. Knee angle was not controlled for on the platform, which could have influenced the transmissibility of the mechanical signal to the axial skeleton. The platform incorporated a desktop, which may have been used as a standing aid or simply to allow the child to read or draw during the intervention. Larger clinical trials are required to confirm the utility of WBV for improving bone mass among children and young adults.

WHOLE-BODY VIBRATION STUDIES AMONG OLDER ADULTS/POSTMENOPAUSAL WOMEN

The literature looking at the effects of WBV on bone health among older adults and postmenopausal women is somewhat inconclusive. Three studies showed no change in bone characteristics following a 6-month (0.1–10 *g*, 12–28 Hz), 12-month (20 Hz), and 12-month (<0.3 *g*, 30 Hz) WBV intervention among postmenopausal women and older postmenopausal women, respectively [33–35]. On the other hand, a small group of studies has reported findings suggesting that WBV may represent an effective nonpharmacological intervention for preventing a decline in BMD or for increasing or maintaining BMD in populations with below-normal BMD or osteoporosis (**Table 2**). Two studies conducted in 2004 and 2006 indicate that WBV may inhibit the decline in BMD of the hip following menopause [36–37]. One study utilizing vertical vibrations reported a 0.93 percent increase in BMD from baseline at the hip following a 6-month WBV intervention (2.28–5.09 *g*, 35–40 Hz) [36]. The other study, utilizing oscillatory alternating vibrations (12.6 Hz, median 3.3 *g* [oscillatory alternating], and 0.7 *g* [vertical]), reported a 4.3 percent increase in BMD at the femoral neck in the group receiving an 8-month WBV intervention compared with the walking control group [37]. Investigators from one of the clinical trials reporting no change in bone characteristics (12 months, <0.3 *g*,30 Hz) later ran a post hoc subgroup analysis that suggested that adherence and body weight may influence the response to the WBV intervention [35]. A recent systematic review and meta-analysis of RCTs on the effects of WBV on BMD in postmenopausal women concluded that WBV appears to effectively attenuate the decline in BMD at the hip [100]. This effect is similar to that of physical activity on BMD, as reported in a study demonstrating that moderate or walking exercise suppressed bone turnover, thereby maintaining lumbar BMD among postmenopausal women [101].

Table 1.
Long-term whole-body vibration (WBV) exposure as an intervention for improving indexes of bone strength among young adults.

Study	Population: *N* (M/F); Type	Methods/Intervention	Plate/Parameters	Frequency & Duration	Outcomes
Torvinen et al., 2003 [1]	56 (21 M/35 F); young, healthy, nonactive	1. WBV 2. CON WBV did light exercise on platform (light squatting, standing with knees flexed, light jumping, etc.)	Kuntotäry, Erka Oy, Kerava, Finland; 25–45 Hz, 2 mm, 2–8 *g* (↑ with time)	3–5×/wk for 8 mo, 4 min/session	No change in any bone density (DXA, pQCT) or serum markers (bone formation: OC, aminoterminal propeptide of type I procollagen; bone resorption: carboxy-terminal collagen crosslinks, osteoclast-derived TRACP isoform 5b)
Ward et al., 2004 [2]	20 (14 M/6 F); children with CP, MD; age (mean ± SD) = 9.1 ± 4.3 yr; limited mobility but stand independently	1. WBV 2. PL Standing position on platform	Vertical, ground-based vibration; 90 Hz, 0.3 *g*	5×/wk for 6 mo, 10 min/session	WBV: ↑ proximal tibia vTBMD (+6.3%) PL: ↓ proximal tibia vTBMD (–11.9%)
Gilsanz et al., 2006 [3]	48 (0 M/48 F); young with low BMD; age (range) = 15–20 yr; history of at least one skeletal fracture	1. WBV 2. CON	Vertical, sinusoidal acceleration; 30 Hz, 0.3 *g*	At least 2 min/d for 12 mo (preferably 10 min/d)	WBV: ↑ trabecular bone in lumbar vertebrae (+2.1%), ↑ cortical bone in femoral midshaft (+3.4%) CON: ↑ trabecular bone in lumbar vertebrae (+0.1%), ↑ cortical bone in femoral midshaft (+1.1%)
Pitukcheewanont & Safani, 2006 [4]	8 (0 M/8 F); children; DM: *n* = 7, idiopathic osteoporosis: *n* = 1	1. WBV Upright standing position	Smith & Nephew; 30 Hz, 0.3 *g*	3×/wk for 8 wk, 30 min/session	↑ trabecular BMD (+6.2%), ↑ cortical BMD (+2.1%)

1. Torvinen S, Kannus P, Sievänen H, Järvinen TA, Pasanen M, Kontulainen S, Nenonen A, Järvinen TL, Paakkala T, Järvinen M, Vuori I. Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: A randomized controlled study. J Bone Miner Res. 2003;18(5):876–84. [PMID: 12733727] DOI:10.1359/jbmr.2003.18.5.876
2. Ward K, Alsop C, Caulton J, Rubin C, Adams J, Mughal Z. Low magnitude mechanical loading is osteogenic in children with disabling conditions. J Bone Miner Res. 2004;19(3):360–69. [PMID: 15040823] DOI:10.1359/JBMR.040129
3. Gilsanz V, Wren TA, Sanchez M, Dorey F, Judex S, Rubin C. Low-level, high-frequency mechanical signals enhance musculoskeletal development of young women with low BMD. J Bone Miner Res. 2006;21(9):1464–74. [PMID: 16939405] DOI:10.1359/jbmr.060612
4. Pitukcheewanont P, Safani D. Extremely low-level, short-term mechanical stimulation increases cancellous and cortical bone density and muscle mass of children with low bone density: A pilot study. Endocrinologist. 2006;16(3):128–32. DOI:10.1097/01.ten.0000217885.60398.27

BMD = bone mineral density, CON = control, CP = cerebral palsy, DM = diabetes mellitus, DXA = dual energy X-ray absorptiometry, F = female, M = male, MD = muscular dystrophy, OC = osteocalcin, PL = placebo, pQCT = peripheral quantitative computed tomography, SD = standard deviation, vTBMD = volumetric trabecular bone mineral density.

LIMITATIONS AND CONCLUSIONS

Limitations in WBV research do exist. Diverse study design and choice of intervention likely account for the discrepancies in outcomes following WBV exposure. Examples of factors that are inconsistent in study design include direction of vibration, range of vibration parameters selected, duration of WBV exposure, length of WBV intervention, frequency of intervention, type/brand of platform used, participant demographic and health-related characteristics, movement performed during exposure, body posture, and research design and outcome measures. In addition, very few of the studies listed here conducted an intention-to-treat analysis. The absence of this analysis may have introduced bias in the results and an overestimation of treatment effects. Study design characteristics should not be overlooked, because variations between protocols limit the generalizability of the findings.

In the future, WBV platform manufacturers should be encouraged to publish their findings from phase I and II clinical trials. In addition, clinicians need to conduct more rigorous phase III RCTs held to the same standard as

Table 2.
Long-term whole-body vibration (WBV) exposure as an intervention for improving indexes of bone strength among older adults and post menopausal women.

Study	Population: *N* (M/F); Type	Methods/Intervention	Plate/Parameters	Frequency & Duration	Outcomes
Russo et al., 2003 [1]	29 (0 M/29 F); postmenopausal on HRT	1. WBV (*n* = 14) 2. CON (*n* = 15) Standing position on WBV platform; RCT	Galileo 2000 (lateral oscillations); 12–28 Hz, 0.1–10.0 *g*	2×/wk for 6 mo, 3 × 2 min/session	No change in bone characteristics; decline in cortical BMD tended to be less in WBV than CON group
Verschueren et al., 2004 [2]	70 (0 M/70 F); postmenopausal (58–74 yr), no disease or medicines affecting bone metabolism	1. WBV (*n* = 25) 2. RES (*n* = 22) 3. CON (*n* = 23) WBV performed static & dynamic knee-extension exercises RES performed dynamic leg press & leg-extension exercises; RCT	Power Plate®; 35–40 Hz, 1.7 or 2.5 mm, 2.28–5.09 *g*, progressive increase	3×/wk for 6 mo, maximum 30 min/session (progressive increase)	WBV: ↑ BMD of hip (+0.93%); net benefit of 1.5% compared with controls; no change in bone turnover markers (OC, C-telopeptide)
Rubin et al., 2004 [3]	56 (0 M/56 F); 3–8 yr post-menopause	1. WBV (*n* = 28) 2. PL (*n* = 28) Double-blind study	Vertical, ground-based vibration; 30 Hz, 0.2 *g*	2 × 10 min/d for 12 mo	No change in BMD
Iwamoto et al., 2005 [4]	50 (0 M/50 F); postmenopausal with osteoporosis & chronic back pain (55–88 yr)	1. WBV + ALN 2. ALN Standing position on platform; ALN = 5 mg/d	Galileo; 20 Hz	1×/wk for 12 mo, 4 min/session	No change in lumbar BMD or urine or serum markers of bone turnover between groups
Gusi et al., 2006 [5]	28 (0 M/28 F); 5 yr postmenopause, untrained	1. WBV (*n* = 14) 2. Walking (*n* = 14) Standing position on platform with 60° knee flexion; walking session = 55 min	Galileo 2000 (lateral oscillations); 12.6 Hz, median 3.3 *g* (lateral) and 0.7 *g* (vertical), progressive increase	3×/wk for 8 mo, 6 × 60 s/session with 60 s rest (progressive increase)	WBV: ↑ BMD at femoral neck (+4.3%) compared with walking group; no change in lumbar spine BMD
Corrie et al., 2007 [6]	33 (not specified); older patients, mean age = 80 yr	1. Vertical WBV (*n* = 11) 2. Tilting WBV (*n* = 11) 3. PL (*n* = 11) RCT	Not specified	3×/wk for 12 wk 6 × 60 s/session (progressive increase)	Vertical WBV: ↑ P1NP (marker of bone formation) (+15.2%) Tilting WBV: ↑ P1NP (+20.2%) PL: ↓ P1NP (–1.3%)

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ALN = alendronate, BMD = bone mineral density, CON = control, F = female, HRT = hormone replacement therapy, M = male, OC = osteocalcin, P1NP = procollagen type 1 N-propetptide, PL = placebo, RCT = randomized control trial, RES = resistance training.

pharmaceutical trials. Future studies should follow the Consolidated Standards of Reporting Trials (CONSORT) in an effort to alleviate the problems arising from inadequate reporting of RCTs. CONSORT includes an evidence-based set of guidelines for reporting RCTs, enabling readers to understand a trial's design, conduct, analysis, and interpretation and to assess the validity of its results [102–103].

Animal research provides evidence to suggest that WBV may stimulate mechanotransduction and elicit a bone adaptive response. Although studies demonstrate that WBV may positively affect bone density, any effect of WBV observed in adults is likely due to a prevention of bone loss. In addition, limitations in research design among existing WBV clinical trials in humans limit conclusions or comparisons across studies. Given that the risk of injury or adverse effects is high if inappropriate WBV parameters are used or screening of subjects is inappropriate, evidence-based guidelines for application of WBV parameters are needed to ensure the safety and efficacy of WBV.

ACKNOWLEDGMENTS

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Financial Disclosures: The authors have declared that no competing interests exist.

Funding/Support: This material was based on work supported in part by the Ontario Graduate Scholarship, Canadian Institute for Health Research Frederick Banting and Charles Best Canada Graduate Scholarship, and Ontario Neurotrauma Foundation, grant ONF-SCI-2006-WAVE-445. J. O. Totosy de Zepetnek was the recipient of an Ontario Graduate Scholarship and the Canadian Institute for Health Research, Frederick Banting and Charles Best Canada Graduate Scholarship Master's Award.

Additional Contributions: We acknowledge the support of Toronto Rehabilitation Institute, which receives funding under the provincial rehabilitation research program from the Ministry of Health and Long-Term Care in Ontario.

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Submitted for publication September 30, 2008. Accepted in revised form February 5, 2009.