The Effects of Whole-Body Vibration Training in Aging Adults: A Systematic Review

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ABSTRACT

Background and Purpose: Whole-body vibration (WBV), has become increasingly popular as a form of exercise training. WBV involves the application of a vibratory stimulus to the entire body as opposed to local stimulation of specific muscle groups. The purpose of this review was to assess the evidence concerning the effectiveness of WBV training studies on bone density, muscle performance, balance, and functional mobility in older adults and to discuss potential precautions, safety concerns, and practical clinical considerations of WBV. **Methods:** A literature search of online databases was conducted and methodological quality assessment was performed using the critical appraisal scales developed by Sackett and Jadad on the WBV articles that met the predetermined inclusion criteria. **Results:** The initial search resulted in the retrieval of 196 potential articles. One additional article was found by manual search. After review, 13 studies were identified that met the predetermined selection criteria. **Discussion** Much of the WBV research to date is methodologically weak and should be interpreted with caution. Study protocols have used widely variable WBV parameters which also complicates the studies' interpretation. Some but not all of the studies in this review reported similar improvements in muscle performance, balance, and functional mobility with WBV as compared to traditional exercise programs. Bone studies consistently showed that WBV improved bone density in the hip and tibia but not in the lumbar spine. **Conclusion:** Additional studies are needed to determine safe and effective parameters for WBV training in older adults.

Key Words: elderly, older adults, rehabilitation, whole-body vibration

INTRODUCTION

Whole-body vibration (WBV), or vibration training, has become increasingly popular over the last several years as a method of exercise training. Recently, national marketing campaigns have even promoted the home use of WBV for aging adults.[1] Unfortunately, research on the benefits of WBV is limited and sometimes conflicting. Additionally, risks from any new intervention (including adverse reactions) need to be thoroughly examined. The failure to disclose adverse reactions is an important factor in iatrogenesis with aging adults.

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As its name implies, WBV involves the application of a vibratory stimulus to the entire body as opposed to local stimulation of specific muscle groups. This is usually performed by having a person stand on a vibrating platform. While standing on the platform, various exercises can be performed if desired. The WBV units typically provide their vibration by using either a rotational or vertical stimulus. With rotational vibration, the platform rotates about an anterior-posterior axis so that positioning the feet further apart results in increased amplitude of movement and applies force asynchronously to the left and right foot, similar to standing near the middle of a "teeter-totter." Whole-body vibration units that provide a vertical stimulus have a platform that translates vertically and symmetrically causing simultaneous movement of the lower extremities in the same direction.[2] In addition to the direction of the vibration stimulus (rotational vs. vertical), there are several treatment parameters that are important to consider when using WBV. These include frequency (Hz), amplitude (mm), and duration. Another parameter of importance is vibration magnitude (*g*), which is a measure of the gravitational acceleration imposed on the body. Most commonly, WBV studies have used frequencies ranging from 25-50 Hz, amplitudes from 2-10 mm, and total durations of 30 sec – 10 min.[3] Currently there is no consensus regarding the optimal parameters needed to achieve a specific physiological response.

The most common use of WBV has been to improve physical performance in athletes and younger adults by enhancing muscle activity, strength, and power associated with traditional neuromuscular training.[3-5] It has been hypothesized that improvements in muscle strength and power after WBV may be related to an increase in neuromuscular activation during and following WBV. Nishihira et al[6] have speculated that mechanical vibration elicits a myotactic stretch reflex which is mediated by the muscle spindle and its Ia-afferents. In a recent study by Abercromby et al,[2] subjects performed unsupported dynamic squats while exposed to either vertical or rotational WBV at 30 Hz and 4mm of amplitude. These parameters elicited a significant increase in EMG activity during the vibration stimulus in the knee flexors and extensors as well as the ankle plantar flexors and dorsiflexors when compared to performing the same movement without vibration. However, it remains unclear if the enhanced muscle activation associated with WBV is primarily due to neural factors (eg, increase in muscle spindle activation) or if other factors such as maintaining a stable posture and dampening of mechanical energy also play a significant role.[2]

Some researchers have evaluated the immediate effects of a single exposure to WBV in younger adults and have shown transient improvements in muscle performance,[4,5,7-9] while others have found little or no effect.[10,11] Investigations involving chronic exposures (11-12 wks) to WBV in younger adults have also shown mixed results. Delecluse et al[12] compared the effects of a 12-week WBV training program to a traditional strength training program in younger females and found similar improvements in muscle performance. In contrast, de Ruiter et al[13] showed no improvements in muscle performance or jump height following an 11-week WBV protocol using similar WBV training parameters.

While most research on the use of WBV has focused on changes in muscle function and athletic performance, there is growing body of evidence that WBV may also influence other physiological systems. For example, Rubin et al[14,15] found that a combination of low magnitude and high frequency vibration increased the anabolic activity of bone, specifically bone density and bone formation in adult female rats. Transient changes in hormonal levels, including an increase in testosterone and growth hormone, have been observed in younger adults following a single 10 min WBV exposure.[16] Exercise combined with WBV has also been shown to increase muscle blood flow volume to the quadriceps and gastrocnemius and possibly delay muscle oxygen desaturation when compared to performing similar exercises without vibration.[17,18]

More recently, researchers have begun to study the effects of WBV in aging adults, including its effects on bone density, muscle performance, balance, and functional mobility. The primary purpose of this review paper is to provide a summary of the current literature, elucidate potential precautions and safety concerns, and discuss practical considerations for the clinical use of WBV with aging adults.

METHODS

Data Sources and Searches

A systematic literature search and review was performed using the bibliographic databases MEDLINE and the *Cumulative Index to Nursing and Allied Health Literature* (CINAHL). These databases were accessed online from September 2006 through December 2007. The search was not limited to any particular language of publication and covered the time period from 1950 to December 2007 for Medline, and 1982 to December 2007 for CINAHL.

Key words used in the search included "whole," "vibration," "older," "elderly," "geriatrics," "bone," "stroke," and "high." The "AND" operator was used in the basic field. Results of the initial search are summarized in Table 1. In addition, a manual search was conducted of the retrieved articles for potential studies that were overlooked or absent from the databases with the result that one additional study was found.

Table 1. Number of Articles found During Initial Search

Operators	Medline	CINAHL
whole AND vibration AND older	9	2
whole AND vibration AND elderly	10	3
whole AND vibration AND geriatrics	2	0
whole AND vibration AND bone	37	5
high AND vibration AND bone	105	11
whole AND vibration AND stroke	8	4

Study Selection Criteria

The titles and abstracts of these references were then examined and articles that did not meet all of the criteria defined for this review were eliminated. Review criteria included: (1) experimental or quasi-experimental reports, (2) studies involving human subjects 60 years of age or older, (3) studies involving vibration of the entire body, (4) training studies of at least a 6 week duration, and (5) studies involving at least one of the following areas: bone density, muscle performance, balance, and functional mobility. Thirteen of the initially identified studies (n=196) met the criteria for review.

Quality Assessment

The methodological quality of the 13 selected articles was assessed by each author independently using the levels of evidence as described by Sackett[19] and the Jadad scale.[20] The results of the quality assessments were compared and any inconsistencies were then resolved by a further analysis of the articles.

The articles were assigned to a particular level as described by Sackett et al[19] (Figure 1). In addition, each article was evaluated using the Jadad scale[20] which has been previously validated as a tool to assess the quality of RCTs in pain studies. The authors suggest that this scale could be used in other areas as well. This scale focuses on randomization, blinding, withdrawals, and dropouts to determine the quality of research studies. The Jadad scale uses a score from 0 to 5 to assess the quality of the trial, with a score of 3 or higher indicating that the RCT is of high quality and a score below 3 indicating a methodologically weak RCT.

Level	Criterion
1A	Systematic Review of RCT*
1B	RCT with narrow confidence intervals
1C	all or none case series
2A	systematic review of cohort studies
2B	cohort study of low quality
2C	outcomes research
3A	systematic review of case-controlled studies
3B	case-controlled study
4	case series, poor cohort case controlled study
5	expert opinion

* RCT = Randomized Controlled Trial

Figure 1. Summary of Sackett's Level of Evidence[19]

RESULTS

Initially, 196 articles were identified for potential review using the MEDLINE and CINAHL databases. Of these articles, 12 were determined to fit the inclusion criteria,[21-32] and one additional article was discovered using a manual search.[33] The results of the quality review are found in Table 2. Using the critical appraisal criteria developed by Sackett et al,[19] 5 studies were rated as 1B, 6 studies were rated as 2B and 2 studies were rated as 4. The quality of the articles was also assessed by using the Jadad scale.[20] Individual article scores ranged from 0 to 5. Major characteristics of the 13 selected articles are summarized in Table 3, organized alphabetically according to vibration type. For review and discussion, articles were carefully read by each author and categorized as pertaining to: (1) bone density, (2) muscle performance, or and (3) balance and functional mobility. A number of articles assessed impact of WBV on more than one of these categories. For these articles, the relevant sections of the study were included in each of the appropriate categories, to facilitate comparison between the selected studies.

Table 2. Levels of Evidence of Selected Whole-Body Vibration Studies in Aging Adults

Study	Level of Evidence: Sackett et al[19]	Level of Evidence: Jadad et al[20]	Study	Level of Evidence: Sackett et al[19]	Level of Evidence: Jadad et al[20]
Rotational Vibration (Galileo)			**Vertical Vibration (Powerplate)**		
Bruyere et al,[21] 2005	2B	2	Bautmans et al, [28] 2005	1B	3
Cheung et al,[22] 2007	1B	3	Bogaerts et al, [29] 2007	2B	2
Gusi et al,[23] 2006	2B	2	Roelants et al, [30] 2004	2B	2
Iwamoto et al,[24] 2005	2B	1	Verschueren et al, [31] 2004	2B	2
Kawanabe et al,[25] 2007	4	0	**Vertical Vibration (low-magnitude)**		
Runge et al,[33] 2000	4	1	Rubin et al, [32] 2004	1B	5
Russo et al,[26] 2003	1B	3			
van Nes et al,[27] 2006	1B	5			

Table 3. Overview of Selected Whole-Body Vibration Studies in Aging Adults

Study	Subjects & Age	Duration	Parameters	Study Design	Main Outcome Measures	Results
Rotational Vibration (Galileo)						
Bruyere et al,[21] 2005	Nursing home residents (n=42) Mean age = 82	6 weeks	10 Hz and 26 Hz 3 sessions/wk each session = 4 x 60 sec with 90 sec break	Control--PT alone Intervention--WBV & PT Each group received PT 3x/wk, each PT treatment was 10 min of standard ex	Tinetti POMA Timed Up and Go (TUG)	Significant improvement with WBV group with Tinetti (both gait & balance sections) and TUG Note that with the WBV group the POMA score improved from 14.9 to 20.5 which is above the fall risk threshold of 19
Cheung et al,[22] 2007	Community-dwelling females (n = 69) Mean Age = 72	3 months	20 Hz 3 sessions/wk 3 min/session	Control--remained sedentary Intervention--WBV alone	Basic balance master system Functional reach test (FRT)	Significant improvement with WBV group using basic balance system in movement velocity, maximal point excursion and directional control Non-significant improvement with FRT in the WBV group
Gusi et al, [23] 2006	Community-dwelling post-menopausal women (n = 28) Mean Age = 66	8 months	12.6 Hz 3 sessions/wk 6 min/session by week 5 to study's end (initial training started at 3 min and progressed to 6 min) each 1 min bout followed by 1 min rest	Control--walking for 1 hour including 10 min of stretching ex Intervention--WBV including 10 min warm-up activities	Bone mineral density (BMD) of proximal femur (femoral neck, trochanter & Ward's triangle) & lumbar spine Blind flamingo test (balance)	BMD only at femoral neck for WBV group reached statistical significance; other hip sites showed non-significant improvement; lumbar spine BMD unchanged Significant improvement in balance with WBV group
Iwamoto et al, [28] 2005	Community-dwelling post-menopausal women (n=50) Mean Age = 71	12 months	20 Hz 1 session/wk each session = 4 min	Control--alendronate alone Intervention--WBV & alendronate	Lumbar bone mineral density (BMD) Serum alkaline phosphatase (ALP)--bone formation Urinary cross-linked N-terminal telopeptides of type I collagen (NTX)--bone resorption Chronic back pain Vertebral fractures	Significant increase in lumbar BMD in both groups Significant decrease in NTX in both groups Significant decrease in ALP in both groups Significant decrease in chronic back pain in WBV group as compared to the control group No increase in vertebral fractures in thoracic and lumbar spine from pre- to post-intervention times in any subject
Kawanabe et al,[25] 2007	Community-dwelling (n=67) Mean Age = 72	2 months	12-20 Hz 1 session/wk 4 min/session	Control--ex alone (= walking 2x/wk) Intervention--WBV & ex (= walking 2x/wk) Walking time was 30 min Ex was for balance and lower extremities for both groups	Walking speed Step length One-legged stance test	Significant increase with WBV group with walking speed, step length and one-legged stance test

Runge et al,[33] 2000	Community-dwelling (n = 34) Mean Age = 67	2 months	27 Hz 3 sessions/wk each session = three 2 min bouts	Control--no WBV Intervention--WBV alone Crossover study--all participants were studied for 2 months as control and 2 months as WBV intervention groups	Chair rising (5x as quick as possible without arms)	Improved chair rising times with WBV group
Russo et al,[26] 2003	Community-dwelling post-menopausal women (n=29) Mean Age = 61	6 months	12-28 Hz (28 Hz for last 5 months) 2 sessions/wk each session = three 1-2 min bouts (2 min for last 5 months)	Control--standing on WBV machine with no WBV Intervention--WBV alone Both groups received supplemental calcium carbonate & vitamin D throughout the study	Muscle force and power (measured as subject jumped on forceplate) Tibial cortical bone density	Significant increase with WBV group in muscle power, but no significant change in muscle force Significant decline in tibial cortical bone density in control group, but stable in WBV group
van Nes et al,[27] 2006	Post-stroke patients in rehab (n = 53) Mean Age = 61	6 weeks	30 Hz 5 sessions/wk each session = 4 x 45 sec with 1 min break	Control--stand on WBV machine with no WBV while listening to exercise on music tapes Intervention--WBV either standing or squatting with buttocks supported on height-adjusted bench Both groups received regular PT and OT treatments throughout the study	Berg balance (primary) Barthel index Functional ambulation categories (FAC) Motricity index Rivermead mobility index Somatosensory threshold Trunk control test	No clinically relevant or statistical differences between the control and WBV groups were observed in all outcome measures Both groups showed statistically significant improvements at study completion as compared to baseline levels in all outcome measures
Vertical Vibration (Powerplate)						
Bautmans et al,[28] 2005	Nursing home residents (n = 24) Mean Age = 77	6 weeks	30-40 Hz 3 sessions/wk each session = 30-60 sec for 2-7 total min with 30-60 sec rest breaks	Control--progressive lower limb ex + motor sound audio tape of WBV while standing on inactive WBV unit Intervention--WBV = progressive lower limb ex	Timed Up and Go (TUG) POMA Dominant hand grip strength Back scratch Chair sit-and-reach Isokinetic bilateral leg extension	Significant improvement with WBV group with both Tinetti (balance & total sections) and TUG No significant changes with hand grip strength, back scratch, chair sit-and-reach and isokinetic bilateral leg extension
Bogaerts et al,[29] 2007	Community-dwelling men older than 60 years (n=97) Mean Age + 68	1 year	35-40 Hz 3 sessions/wk Each session 40 min	Control--no lifestyle change Fitness (FIT)--1.5 hr of ex, 3x/wk WBV Intervention--WBV = ex; note that ex was a maximum of 40 min during WBV intervention Fitness (FIT)--1.5 hr of ex, 3x/wk	Isometric knee extension Explosive strength using counter movement jump (CMJ) Muscle mass of R upper thigh	Significant increase with isometric knee extension in FIT and WBV groups Significant increase with explosive strength in the FIT and WBV groups Significant increase with muscle mass in FIT and WBV groups Note that the training effects were similar between the FIT and WBV groups for all 3 outcome measures
Roelants et al,[30] 2004	Community dwelling post-menopausal women (n = 89) Mean Age = 64	24 weeks	35-40 Hz 3 sessions/wk each session = 30-60 sec for 3-30 min total with 5-60 sec rest breaks; WBV times progressed during study	Control--no ex or no WBV Resistance group (RES)--progressive total body ex WBV Intervention--WBV = progressive total body ex	Knee extensor strength--isometric & dynamic Knee extensor speed of movement Explosive strength using counter movement jump (CMJ)	Significant increases with isometric and dynamic knee extensor strength as well as explosive strength in both RES and WBV groups Significant increase in knee extensor speed of movement at lower resistance levels in only the WBV group Most of the gains in knee extensor strength & speed of movement and in CMJ explosive strength observed at 24 weeks were realized after just 12 weeks of training

Verschueren et al,[31] 2004	Community dwelling post-menopausal women (n = 70) Mean Age = 64)	24 weeks	35-40 Hz 3 sessions/wk each session = up to 30 min WBV including warmup and cool down; WBV times progressed during study	Control--no ex Resistance group (RES)--progressive lower extremity ex for 1 hour WBV Intervention--WBV = progressive lower extremity ex	Bone mineral density (BMD) of hip, lumbar spine and total body Lean body mass, fat mass, % fat Isometric & dynamic knee extension strength Bone markers--osteocalcin (formation) & C-telopeptide (resorption)	Significant net benefit with hip BMD in WBV group only; no significant change in total body and lumbar spine with any group Significant decreases in fat mass with both RES and WBV groups Significant increases with isometric and dynamic knee extensor strength in both RES and WBV groups No significant changes with bone markers
Vertical Vibration (low-magnitude)						
Rubin et al,[32] 2004	Community dwelling post-menopausal women (n = 70) Mean Age = 57	1 year	30 Hz 14 sessions/wk 2 sessions/day each session = 10 min	Control--standing on placebo (no vibration) machine that emits audible sound WBV Intervention--WBV on vibrating machine that emits audible sound	Bone mineral density (BMD) at proximal femur, lumbar spine	Significant effect of compliance on efficacy of the intervention, especially at the lumbar spine With subjects in the highest compliance quartile, WBV group versus the placebo group showed near significant net relative benefit in BMD at the femoral neck and lumbar spine

Bone Density

Five studies that met the search inclusion criteria[19] specifically related to bone density.[23,24,26,31,32] Based on Sackett's criteria,[19] Russo et al[26] and Rubin et al[32] were rated as 1B, while Gusi et al,[23] Iwamoto et al,[24] and Verschueren et al[31] were rated 2B. Using the 0-5 rating of the Jadad scale,[20] the scores of these articles were 1, 2, 3, or 5.

Gusi et al[23] used low-frequency rotational WBV (12.6 Hz) in an RCT with 28 community-dwelling postmenopausal women (mean age 66). Participants were assigned to either a WBV group or walking group that met 3 times/week for 8 months. The WBV group first warmed up for 10 minutes total (bicycling and stretching exercises) and were then exposed to 6 bouts of 1 minute vibration. The walking group trained outdoors. Each 1-hour session of walking was interspaced with two 5 minute periods that included stretching exercises. After 8 months, BMD at the femoral neck increased by 4.3% ($p = 0.011$) in the WBV as compared to the walking group, however, lumbar spine WBV was unchanged in both groups.

Iwamoto et al[24] used rotational WBV (20 Hz) in a RCT of 50 postmenopausal women with osteoporosis (ages 55-88 year old; mean age 71). All women in this study were taking 5 mg daily of the antiresorptive alendronate.[24] Additional measurements taken included serum calcium and phosphorus levels, urinary cross-linked N-terminal telopeptides of type I collagen (NTX), a bone resorption marker, and serum alkaline phosphatase (ALP), a bone formation marker. Half of the women were also exposed to 4 minutes of 1 time/week WBV for 12 months while continuing alendronate. Similar significant longitudinal changes were found in both groups at 6 and 12 months as compared to baseline, with lumbar BMD increasing and urinary NTX and serum ALP decreasing. Serum calcium and phosphorus levels did not change significantly in either group.[24] The study's authors suggest that it is not surprising that no change in BMD occurred between the groups since the WBV exposure time was limited to 4 minutes a week. One difference found between the groups was that the WBV subject group reported a significantly greater decrease in chronic back pain ($p < 0.05$) using a 10-point face pain scale. X-rays that were taken at the end of 12 months of treatment showed no additional vertebral fractures for the T4-L4 spine indicating that the parameters used in this study were safe in osteoporotic subjects.

Russo et al[26] used rotational WBV in an RCT to evaluate the effect of WBV on tibial bone density using peripheral quantitative computed tomography in 29 community-dwelling postmenopausal women. To insure that participants were not deficient in calcium or vitamin D, they received daily supplements of 1g of calcium carbonate and 0.25µg of activated vitamin D (calcitriol) for 3 months prior to WBV intervention; supplementation continued during the 6 month study period. Tibial cortical bone density remained stable in the WBV group, but significantly declined in the control group ($p < 0.05$). Bone parameters including bone turnover markers did not change significantly in either group.

Verschueren et al[31] in a randomized, double-blind, and placebo-controlled trial, measured bone density in 70 postmenopausal women ages 58-74 year old (mean age 64). Those women in the vertical WBV (35-40 Hz) group and resistance training group trained 3 times/week for 24 weeks while the control group did not participate in any training. The women who were in the WBV group also performed static and dynamic knee-extensor exercises during exposure to WBV. Whole-body vibration varied in intensity, amplitude, and duration (maximum of 30 minutes) from session to session. Only the WBV group showed a significant 1.5% net benefit in bone mineral density (BMD) using DXA at the hip as compared to both the resistance training ($p < 0.05$) and control groups ($p < 0.01$). Total body BMD and lumbar spine BMD did not change over time in any of the 3 groups. In addition, serum markers of bone turnover (osteocalcin for bone formation and C-telopeptide [CTX] for bone resorption) did not change for any group indicating that WBV may have a local effect (at the hip) rather than a systemic effect on BMD.

In a one year randomized, double-blind, and placebo-controlled study of 70 postmenopausal women (mean age 57) in a home-environment, Rubin et al[32] exposed the experimental group to low-magnitude (0.2*g*) high-frequency vertical vibration (30 Hz) while the placebo group stood on a similar device that did not vibrate. Note that in this low-magnitude vibration study, the g forces were 12 to 50 fold less than other WBV studies that used high-magnitude vibration in the range of 2.5-10*g*.[26,31] Subjects were instructed to stand on their device for two 10 minute treatments/day, separated by a minimum of 10 hours, for 7 days/week. Subject compliance varied greatly from 1% to 95% with 28 women in each group completing the 1 year study. This had a significant effect on efficacy of treatment, especially at the lumbar spine ($p = 0.004$). Subjects who were in the highest quartile of compliance showed a BMD net relative benefit of 2.17% ($p = 0.06$) and 1.5% ($p = 0.09$) at the femoral neck and lumbar spine, respectively.

Muscle Performance

Five of the studies (see Table 2 and Table 3) that met inclusion criteria specifically related to muscle performance.[26,28-31] According to Sackett and Jadad assessments, Russo et al[26] and Bautmans et al[28] were rated 1B and 3, while Bogaerts et al,[29] Roelants et al,[30] and Verschueren et al[31] were rated 2B and 2.

In a study that focused on changes in muscle power, Russo et al[26] investigated the effects of rotational WBV on 29 community-dwelling postmenopausal women (mean age 61). In this 6 month long RCT, participants were divided into 2 groups: the control group received no training and the intervention group was exposed to increasing amounts of WBV twice weekly. The intervention began with 3 minutes total exposure in 1 minute increments at 12 Hz progressing to 6 minutes total exposure in 2 minute increments at 28 Hz. Muscle power was assessed by having participants jump as high as possible and land on a force plate that measured ground reaction forces; muscle force and velocity were calculated from the muscle power measurements. The WBV group, based on mean (SE) values demonstrated about a 5% ($p < 0.02$) improvement in muscle power starting from 178.9 (9.6)W at baseline to finishing at 187.3 (9.5)W at post-test, while the control group showed a slight decline. Velocity also significantly increased in the WBV group ($p < 0.005$) beginning at 163.7 (6.2)m/s at baseline and progressing to 171.7 (5.3)m/s at post-test, though muscle force showed no significant change in either group.

Roelants et al[30] used vertical WBV in a study of 89 community-dwelling postmenopausal women (mean age 64). In this 24-week randomized controlled trial, subjects were divided into 3 groups; a control group that underwent no training, a resistance-training group (RES) that trained progressively for 1 hour 3 times/week using guidelines established by the American College of Sports Medicine and a WBV group that also trained progressively 3 times/week with 3 to 30 minutes of vibration (35-40Hz) exposure. The WBV group also performed a progressive total-body-training program of unloaded static and dynamic exercises during WBV consisting of high squat, deep squat, wide-stance squat, and lunge exercises. Isometric and dynamic strength as well as speed of movement (at 1%, 20%, 40% and 60% of isometric maximum) of the right knee extensors were measured by a motor-driven dynamometer, with subjects seated on a backward-inclined (15^{o}) chair. Lower-limb explosive performance capacity was determined by having subjects jump up in the air with their hands placed at the waist in what is known as a vertical counter-movement jump (CMJ) test. Counter-movement jump was performed on a contact mat which calculated the flight time in milliseconds as the elapsed time between when the feet left the mat to the time the feet reestablished contact. Isometric and dynamic knee extensor strength increased significantly ($p < 0.001$) in both the WBV and RES groups, however, training effects were not different between these two groups. Knee extensor speed of movement was significantly increased in the WBV group alone, but only at low resistance (1% and 20% of isometric maximum). Counter-movement jump height showed a statistically significant increase ($p < 0.001$) in both WBV and RES groups. Most of the gains described above were realized during the first 12 weeks of training.

In a RCT focused on the effects of vertical WBV on 97 community-dwelling older men (mean age 68), Bogaerts et al[29] compared WBV to fitness training (FIT). Both WBV and FIT groups trained for 3 times/week for 1 year. The WBV group performed progressive exercises on the vibration platform (35-40 Hz), while the FIT group performed cardiovascular, resistance, balance, and flexibility exercises for about 1.5 hours/session following the American College of Sports Medicine guidelines. The control group did not change their lifestyle or physical activity during the study. Isometric unilateral knee extension strength was tested by an isokinetic dynamometer, explosive strength was assessed by counter movement jump and muscle mass of the right upper leg was measured by multi-slice computed tomography. Isometric strength increased significantly in the WBV group (9.8%, $p = 0.005$) and in the FIT group (13.1%, $p < 0.001$) while no changes were found in the control group. Counter-movement jump performance also increased significantly ($p < 0.001$) in both the WBV group (10.9%) and FIT group (9.8%), while no significant changes were found in the control group (1.8%). Muscle mass changed significantly ($p < 0.001$) in both WBV (3.4%) and FIT (3.8%) groups, with no changes in the control group (-0.7%). The training effects were similar between the FIT and WBV group for all 3 outcome measures.

Bautmans et al[28] studied the effects of vertical WBV (30-40 Hz) on 24 nursing home residents (mean age 77) over 6 weeks in a RCT. Subjects were divided into control and intervention groups. Each group performed 6 static lower limb exercises with the exercise volume and intensity progressively increased according to the overload-principle. The control group was not actually exposed to WBV, but was played the sounds of the WBV motor during the exercise time while standing on the machine. The WBV group performed the same exercises as the control group, but did so while being exposed to WBV (30-40 Hz), progressing from an initial WBV exposure of 2 minutes to 7 minutes during the last week of the study. Functional outcomes included dominant hand maximal grip strength, upper and lower body flexibility using the back scratch and chair sit-and-reach tests, and closed chain bilateral leg extension performance using a multi-joint dynamometer. No significant changes were observed between the WBV and control groups. The researchers found a high rate of compliance (96%) during the study with the WBV group, suggesting WBV is feasible as intervention for deconditioned populations such as nursing home residents.

Verschueren et al[31] also compared the effects of vertical WBV and resistance training on knee extensor strength as evaluated by a motor-driven dynamometer. Specifically, isometric strength of the knee extensors increased by 15% ($p < 0.001$) in the WBV group and by 16% ($p < 0.001$) in the resistance training group over the 24-week study period. In contrast, isometric strength in the control group showed a 2% nonsignificant decline ($p = 0.57$). Knee extensor dynamic strength increased significantly ($p < 0.001$) by 16.5% in the WBV group and by 10.6% in the resistance training group, while a nonsignificant change of +2.2% ($p = 1.14$) was observed in the control group.

Balance and Functional Mobility

Seven studies considered the effect of WBV on balance and functional mobility.[21-23,25,27,28,33] According to Sackett's criteria, Cheung et al,[22] van Nes et al[27] and Bautmans et al[28] were rated as 1B level of evidence. The work of Bruyere et al[21] and Gusi et al[23] was rated as 2B, while that of Kawanabe et al[25] and Runge et al[33] was rated 4. Using the Jadad scale the scores from these studies ranged from 0 to 5.

Runge et al[33] was one of the first researchers to study the effects of rotational WBV (27 Hz) on function. Subjects included 34 community-dwelling ambulatory seniors (mean age 67). Primary outcome measurement was timed sit to stand performance (how fast the subject could rise from a chair 5 times with arms folded across the chest). In this cross-over design study, each subject participated in a WBV program for 2 months and a control period for 2 months. The intervention group was exposed to WBV 3 times/week, with each session consisting of 3 periods of 2 min WBV exposure. After 2 months of intervention, the WBV group showed an 18% improvement in chair rising times as compared to the control group.

Bruyere et al[21] studied the effect of rotational WBV (combination of 10 Hz and 26 Hz) on balance and gait using the Performance-Oriented Mobility Assessment (POMA/Tinetti) and Timed Up & Go (TUG) tests. There were 42 subjects in this RCT of nursing home residents (mean age 82) that were divided into either a physical therapy (PT) group alone or a combined PT and WBV group. Physical therapy consisted of gait and balance exercises, transfer training and lower extremity resistive mobilization. Each group received PT 3 times/week for 10 minutes but the WBV group also underwent vibration for 4 x 1 minute, 3 times/week for the duration of the 6 week study. The WBV group showed statistically significant improvements using mean (SD) values as compared to the control group ($p < 0.001$) in both POMA gait score by 2.4 (2.3) points and POMA balance score by 3.5 (2.1) points. The TUG test time decreased significantly ($p < 0.001$) by 11.0 (8.6) seconds in the WBV group as compared to an increased test time of 2.6 (8.8) seconds in the control group.

van Nes et al[27] investigated the effects of rotational WBV (30 Hz) on 53 patients with stroke (mean age 61) during post-acute rehabilitation. Subjects selected for this RCT had moderate to severe functional disabilities as defined by a score of less than 40 on the Berg Balance Scale. They were divided into a music-based exercise group (ETM) and a WBV group 5 times/week (4 x 45 sec WBV per session) for 6 weeks. Both groups received their regularly scheduled physical and occupational therapy treatments throughout the study. Outcomes measures included the Berg Balance Scale, Trunk Control Test, and Rivermead Mobility Index. While both groups (ETM and WBV) showed statistically significant improvements as compared to baseline values, no clinically relevant or statistically significant between group differences in outcomes were observed.

Cheung et al[22] investigated balance in 69 community-dwelling elderly women (mean age 72) in an RCT where the rotational WBV intervention group (20 Hz) received vibration alone 3 times/week for 3 minutes each session during this 3-month study. A control group remained sedentary during the study. Stability was assessed using a Basic Balance Master (NeuroCom International Inc.) system. This system measured 5 different parameters as the subject stands on a force plate with arms at the sides and sways their body toward 8 surrounding computer-generated target positions. Briefly, the parameters measured were: (1) reaction time (time between the signal to move and the initiation of movement), (2) movement velocity (average speed of the center of gravity [COG]), (3) endpoint excursion (distance traveled by the COG on the primary attempt to reach the target), (4) maximum excursion (furthest distance traveled by the COG) and (5) directional control (comparison of the amount of movement in the intended direction to the amount of extraneous movement). Significant improvement ($p < 0.01$) was shown in the WBV group as compared to the sedentary control group in both movement velocity and maximum point excursion, while directional control reached a marginal significant level ($p < 0.05$). These parameters are involved in muscle fiber recruitment, muscular adaptation, and neuromuscular coordination. Reaction time and end-point excursion were not significantly different between the groups. The authors also looked at the functional reach test, and found a nonsignificant percent improvement ($p = 0.22$) of 23.77 (63.01) cm in the WBV group versus a 6.59 (34.56) cm control measured using mean (SD) values.

Kawanabe et al [25] undertook a 2 month nonrandomized study of 67 community-dwelling older adults in Japan (mostly female, mean age 72). Subjects were divided into 2 groups, with both groups participating in balance and muscle strengthening exercises and walking for 30 minutes 2 times/week. In addition, the WBV group was exposed to rotational WBV (12-20 Hz) for 4 minutes 1 time/week. At the end of the study, walking speed, step length, and maximum standing time on one leg were significantly improved only in the WBV plus exercise group ($p < 0.05$) but not in the control exercise group.

Gusi et al's[23] study (methods described in detail above in the discussion of bone density) also evaluated the effects of rotational WBV (12.6 Hz) on static balance with eyes closed, using a "blind flamingo test." For this test, the subject stood barefoot with eyes closed on one leg with the other leg's knee positioned in flexion and held in place at the ankle with the same side hand. The number of trials that the subject needed to complete 30 sec of continuous standing in the static position was recorded. The study reported a 29% improvement in balance in the WBV group ($p = 0.023$) but no improvement in the control walking group.

Bautmans et al[28] used a RCT to investigate the effects of vertical WBV on balance over a period of 6 weeks on 24 nursing home residents (mean age 77). Briefly, the subjects were divided into 2 groups, a control group that listened to tape recorded WBV motor sounds and an intervention WBV group, with each group performing lower limb exercises on the vibration unit (see muscle performance section for more study details). Balance was assessed using the TUG and POMA tests. The WBV group showed a statistically significant improvement with the TUG (p = 0.029), POMA body balance (p = 0.001), and POMA total score (p = 0.002).

While the duration of most of these balance studies was only 6 to 12 weeks, most showed that WBV had a statistically significant positive effect on improving balance and functional mobility in seniors. This is a promising finding as fall prevention is a crucial element in preserving quality of life as well as longevity in older adults. Again, there is much variation in protocol design, but the results are encouraging that WBV may be a viable alternative to exercise training in improving balance and functional mobility among sedentary and frail older adults.

DISCUSSION

Bone Density

Osteoporosis is one of the most common diseases facing the aging adults in Western society including United States.[34-36] Various strategies have been recommended to manage this serious health problem including increased dietary or supplemental calcium and vitamin D, promotion of weight-bearing physical activity, and pharmacological intervention.[37,38] Because many current aging adults' participation in physical activity is limited, the use of a convenient modality such as WBV to prevent or to reduce the effects of osteoporosis holds promise.[28,39,40]

For this review, 5 studies were identified that specifically evaluated the training effects of WBV on measures of bone density and bone turnover.[23,24,26,31,32] Training duration ranged from 6 to 12 months and training frequency from 1 time per week to 2 times per day. The time spent training in a given day ranging from 4 to 30 minutes with total WBV exposure times ranging from 3.5 hrs[24] to 840 hrs.[32] With respect to the type of vibration, 3 studies[23,24,26] used devices that delivered a vertical form of vibration and 2 studies[31,32] provided a rotational form of vibration. Vibration frequencies ranged from a relatively low 12.6 Hz[23] to a maximum of 40 Hz[31] and vibration magnitudes ranged from 0.2*g*[32] to 10*g*.[26] It is clearly evident that treatment protocols varied considerably between the studies.

Only one study did not demonstrate benefit from WBV.[24] Not surprisingly, this study by Iwamato et al [24] had the lowest exposure to WBV with subjects only receiving one 4 min session per week. This amount of WBV could have been too low to elicit a significant treatment effect. Additionally, only bone density in the lumbar spine was evaluated in this study, which may be less likely to respond to WBV since Rubin et al[41] has shown that mechanical energy is dissipated as it travels proximally up the body when one stands erect on a vibrating platform.

Four studies[23,26,31,32] showed significant improvements or maintenance of bone density at the hip or tibia following WBV when compared to subjects performing other forms of exercise (walking, strength training) or no activity. None, however demonstrated improvements in lumbar spine density despite much greater exposures to WBV. This strengthens the argument that transfer of mechanical vibration energy from the feet may be insufficient for increasing bone density in the lumbar spine. The study by Rubin et al[32] used a low-magnitude (0.2*g*) vibration compared to the other 3 studies (2-10*g*) but also had by far the greatest total exposure time (840 hr). While the low-magnitude vibration was well tolerated, the twice daily, year-long protocol led to a low compliance rate with only 37% of the subjects achieving greater than 80% compliance. This is an important clinical consideration since only the subjects who had the highest compliance showed statistically significant improvements.

The evidence provided by studies, taken together, suggest that WBV may improve or maintain bone density at the hip and tibia but not at the lumbar spine. It also appears that either vertical or rotational types of WBV can be effective as well as low and higher magnitude vibration. There seems to be a dose-response relationship, with studies using longer exposures to WBV[23,31,32] and participants with higher compliance[32] demonstrating the most consistent benefit. Though the effects of WBV on increasing bone density are promising, further studies are needed to determine the optimal dose response in terms of frequency, magnitude, amplitude, and duration of WBV training protocols to enhance bone formation and/or to decrease bone resorption. From a clinical stand point, treatment compliance and safety is of the utmost importance, so determining the minimal vibration dosage that provides the maximum benefit should be an important consideration when designing future research studies.

Muscle Performance

It is well documented that muscle power and strength decline with age, and the rate of this loss increases with deconditioning. These declines can be minimized by resistance training and stretching exercises; however, as one ages the barriers of fatigue and lack of motivation may grow in significance.[28,42] Whole-body vibration is a potential novel alternative to conventional methods of enhancing muscle performance and flexibility that has been investigated in several studies involving aging adults.

The 5 training studies investigating the effects of WBV on muscle performance used a wide variety of protocols.[26,28-31] Four of the five studies were RCTs that compared muscle performance of subjects who performed specific exercises while exposed to WBV with either subjects who completed the same exercises without WBV or with subjects who underwent traditional strength training and cardiovascular conditioning.[28-31] In general, these studies demonstrated similar improvements in muscle strength and power between the WBV training and traditional exercise regimens; WBV seemed to have similar benefits as other forms of lower extremity strength training but did not necessarily provide any added benefit. In several studies,[29-31] the training time was significantly less for the WBV group (30-40 min per session) than for the traditional exercise group (1-1.5 hrs per session). This suggests that WBV may be a potentially efficient and effective method of training.

It is unclear whether it is necessary to exercise while standing on the vibration unit in order to benefit from WBV training. Based on principles of specificity of training, it would be logical to expect that active exercise during WBV would possibly enhance exercise response. It is not clear whether a patient unable to exercises during WBV because of impaired balance, coordination, weakness, or fatigue would derive benefit from WBV alone. Only Russo et al[26] compared outcomes between subjects who merely stood on the WBV unit 2 times per week to a group who performed no exercise activity. Following the 6 months of training, the WBV group showed significant improvements in muscle power but absolute changes were relatively small (5%) and may be of questionable clinical importance. The small change may be related to dosage: this study had the lowest WBV exposure time (6 minutes, twice per week) among the studies meeting review criteria.

The 2 methods of used to assess muscle performance in this group of studies were isokinetic dynamometry and the CMJ test, both of which focused on performance of knee extensors. Because previous research has shown greater activation of distal musculature during WBV, [43] assessing ankle plantar- and dorsiflexor performance would be an important component of future WBV training studies.

Balance and Functional Mobility

One of the most important goals of physical therapy intervention is to improve function and/or reduce health risks. Seven studies evaluated the effects of WBV on gait, balance, functional mobility and quality of life.[21-23,25,27,28,33] While most found statistically significant improvements in balance and functional mobility, they also had methodological flaws in that they were of relatively low quality. One concern would be the lack of evidence about validity and reliability outcome measures such as the blind flamingo and back scratch test.[23,28]

In many of these studies, both control and intervention groups usually received some other form of exercise or physical therapy during the course of the study.[21,23,25,27,31] These exercises and therapeutic activities were often described as "standard" physical therapy or "routine" strengthening and gave little to no detail regarding the specific exercises and activities. This makes it difficult to determine the possible influence or effect of these exercise activities on treatment response. A more ideal study design may involve each study group performing identical exercises on a WBV unit with one receiving vibration and the other not.

The 3 studies that demonstrated the greatest improvements in functional mobility had the lowest quality scores. Kawanabe et al[25] found a 15% ($p < 0.05$) increase in walking speed after 2 months of receiving WBV for a total 4 minutes once per week. This nonrandomized trial (Jadad score 0) grouped subjects based on their "desire" to use WBV; a threat to internal validity of the study with potential to bias results. Bruyere et al[21] (Sackett rating 2B, Jadad score 2) reported a 11.0 (8.6) second improvement ($p = 0.04$) in TUG, a 7.4 point increase ($p < 0.001$) in overall POMA score, and improvements ($p < 0.05$) in 8 of 9 domains on the SF-36 quality of life scale. There are a number of potential explanations for the large degree of improvement found. This study of nursing home residents (mean age 81.9 years) used a control group receiving "maintenance" physical therapy, and an intervention group receiving both PT and WBV. Physical therapy consisted of 10 minutes of "maintenance" activity 3 times per week; WBV was provided for 4 minutes each session 3 times per week. The WBV plus therapy group received 40% more "activity" than the PT only group. Investigators were not blinded to group membership. This study had, by far, the oldest subjects of any reviewed study; but there was a significant difference in age between the WBV (mean, 84.5 years) and control groups (78.9 years; $p = 0.03$). It may be that frail older adults have greater potential to benefit from a modality such as WBV than younger and possibly more active subjects. Runge et al[33] reported a "highly significant" 18% improvement in the 5-repetition sit to stand test but gave no statistical comparisons to support this finding or measures of variability. The study was not well written, making it difficult to determine if a randomized cross-over design described was actually implemented because of several contradictory statements in the text of the article.

Only 2 of the 7 studies concerning balance and functional mobility were RCTs deemed as high quality (Level 1B, Jadad 3-5). Cheung et al[22] measured postural control with the Basic Balance Master System and the Functional Reach test in a group of subjects receiving WBV and a control group who performed no specific exercise activity. They found significant improvements in movement velocity ($p < 0.01$), maximum excursion ($p < 0.01$), and directional control ($p < 0.05$) on the Balance Master but no significant difference in Functional Reach. van Nes et al[27] investigated if there was any added benefit of using daily WBV with post-acute stroke patients who were also receiving inpatient rehabilitation. While there was no difference in outcomes between the WBV and control groups, daily WBV was well tolerated by subjects with relatively acute strokes.

Precautions and Safety Considerations

As with any therapeutic modalities, WBV has a risk for harmful effects when used improperly and indiscriminately. Chronic exposure to high magnitude WBV in occupational settings can have a negative impact on musculoskeletal, digestive, vascular, reproductive, visual, and vestibular system function.[44-47] These include intervertebral disc displacement, spinal vertebrae degeneration, osteoarthritis, hearing loss, visual impairment, and vestibular damage.[44-47] Vibration exposure can be quantified using an "estimated vibration dose value" (eVDV). This value is calculated using the direction, frequency, magnitude and duration of the vibration (eVDV= 1.4 a rms t 1/4). According to the International Organization for Standardization (ISO), exposure to eVDVs exceeding 17 is potentially harmful. Abercromby et al[2] found that using vibration parameters similar to those used for therapeutic purposes (10 $\text{min}\cdot\text{day}^{-1}$, 30Hz, 4mm amplitude) exceeded ISO standards for vibration exposure. It is important to note that ISO health guidelines focus on chronic exposures of healthy adults to daily vibration and so may have limited value for assessing risk associated with less frequent exposures in older adults.

Abercromby et al[2] compared the potential harmful effects of vertical and rotational forms of WBV, finding that risks associated with rotational vibration may be lower than with vertical vibration. With rotational vibration the mechanical energy transferred to the spine and head can be dampened by flexing and extending the lower extremities in an alternating fashion. Abercromby et al also determined that maintaining knee flexion angles between 26° and 30° while standing on the vibrating platform minimized head acceleration and transfer of mechanical energy to the spine.

Prior to administering WBV, it is critical that patients be carefully screened for possible conditions or co-morbidities that might increase the risk of unintended negative side-effects. Table 4 lists possible conditions and co-morbidities that are common among aging adults and may preclude the use of WBV training. This list was compiled based on the exclusion criteria listed by researchers

Table 4. Co-Morbidities and Chronic Conditions that may Preclude the Use of Whole-Body Vibration Training in Aging Adults

Musculoskeletal	Cardiovascular
Hip or knee endoprosthesis	Recent myocardial infarction
Acute disc herniation	Hypertension
Acute arthritis	Artificial heart valves
Joint fusion with metal implants	Pacemaker
Osteoporosis with vertebral fracture	Venous thrombosis
Recent fracture	Aortic aneurysm
Acute soft tissue injury	Peripheral vascular disease
Neuromuscular	**Other**
Impaired sensation	Malignant tumors
Epilepsy	Acute edema
Impaired cognition	Impaired skin integrity of foot or leg
Deep brain and spinal cord stimulators	Recent surgery
	Incontinence of bowel and/or bladder

in the 13 studies examined in this review. Despite the potential risks associated with WBV, 6 of 13 studies identified no adverse events or unintended side-effects.[23-25,29,31,32] The others reported minor side effects including transient itching and erythemia,[21,26,30] muscle soreness,[22] headache,[22] forefoot pain,[33] groin pain,[28] fear,[28] and mild knee pain.[30] There was one incidence of severe shoulder pain experienced by a subject with stroke; researchers suggested that there was no direct causal relationship between the WBV and the subject's pain.[27] Across all studies, only 8 subjects withdrew for reasons specifically related to the vibration intervention. Only transient itching, erythema and muscle soreness were reported by more than one individual, and these symptoms dissipated within the first 3-10 WBV training sessions.

Practical Clinical Considerations

When considering any new therapeutic intervention, effectiveness and safety are of primary importance. However, other factors such as equipment cost, reimbursement, and compliance need to be considered. In regards to equipment cost, most commercial/clinical vibration units range between \$5,000 - \$12,000 and home units ranging from \$300 - \$3000. Nearly all of the research has used one of two WBV units; the Galileo (Novotec GmbH, Pforzheim, Germany) which provides a rotational sinusoidal vibration or the Power Plate (Power Plate, Amsterdam, Netherlands) which provides a primarily vertical stimulus. While there is not enough data to support the effectiveness of one type of vibration unit over another, there are some practical issues to consider. The rotation vibration provide by the Galileo vibration unit may help to decrease energy transfer to the spine and head which may be a concern, especially with frail older adults. However for some aging adults, the asynchronous nature of the rotational vibration may make it more difficult to perform certain exercises on the platform because both feet must remain on the unit at all times, while exercises such as lunges, step-ups, and single leg stance can be performed more easily on vertical vibration units such as the Power Plate.

Since most aging adults using WBV would be eligible for Medicare benefits, it is important to understand Medicare guidelines regarding the provision of skilled physical therapy services as well as medical necessity as it relates reimbursement for WBV training. If a patient requires careful monitoring and or verbal and manual cues for safe use of WBV, it may be appropriate to classify the activity as a skilled intervention. Additionally, if the patient were performing traditional exercises such as partial squats during WBV in an effort to improve sit to stand transfers, then WBV may be a reasonable and necessary intervention since the patient is performing an exercise with a known benefit (partial squats) to improve an important functional skill even though there is limited evidence supporting WBV. If a patient was deemed safe and independent in the use of WBV or if WBV was being used primarily for maintenance or wellness purposes, the activity would not be considered a skilled service or reasonable and necessary.

Another important clinical consideration for using WBV is patient compliance and comfort. Several studies have demonstrated the potential feasibility of WBV training in older adults. In a study by Roelants et al[30] it was reported that most of the study's subjects, postmenopausal women with an average age of 65 years, found the experience of using vertical WBV (35-40 Hz) over the 24-week study period to be enjoyable and did not consider it to be a difficult activity. Another study detailed compliance of subjects using vertical WBV (30 Hz) in elderly women who lived in a retirement community.[37] Overall, 83% of subjects had $\geq$ 80% compliance. Elderly participants in this study also reported a 95% overall satisfaction with daily use of the vibrating platform and 57% actually preferred the platform versus daily oral medication for preventing bone loss. The women also reported few adverse experiences during this 6-month study.

CONCLUSION

Recently, there has been increased interest in the use of WBV as a form of exercise training for older adults. This systematic review found that most of the research is methodologically weak and should be interpreted with caution. Study protocols have used widely variable WBV parameters which also complicates study interpretation. The long-term (> 1 year) effects of WBV have also yet to be studied. Most of the studies in this review reported that subjects exposed to WBV showed similar improvements in muscle performance, balance, and functional mobility as compared to traditional exercise programs and that WBV provides no added benefit to traditional exercise programs. Studies investigating the effect of WBV on bone density consistently showed that WBV improved bone density in the hip and tibia but not at the lumbar spine. Additional studies are needed to determine safe and effective parameters for WBV training in aging adults.

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REFERENCES

1. Soloflex™ Web site. 2007. Available at: http://www.soloflex.com. Accessed January 2, 2008.

2. Abercromby AFJ, Amonette WE, Layne CS, McFarlin BK, Hinman MR, Paloski WH. Vibration exposure and biodynamic responses during whole-body vibration training. *Med Sci Sports Exerc.* 2007;39:1794-1800.
3. 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.
4. Cardinale M, Bosco C. The use of vibration as an exercise intervention. *Exerc Sport Sci Rev.* 2003;31:3-7.
5. Bosco C, Colli R, Introini E, et al. Adaptive responses of human skeletal muscle to vibration exposure. *Clin Phys.* 1999;19:183-187.
6. Nishihira Y, Iwasaki T, Hatta A, et al. Effect of whole body vibration stimulus and voluntary contraction on motorneuron pool. *Adv Exerc Sports Physiol.* 2002;8:83-86.
7. Bosco C, Cardinale M, Tsarpela O. Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *Eur J Appl Physiol.* 1999;79:306-311.
8. Bosco C, Cardinale M, Tsarpela O, et al. The influence of whole body vibration on jumping performance. *Biol Sport.* 1998;15:157-164.
9. Torvinen S, Kannus P, Sievanen 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.
10. Cormie P, Dean RS, Triplett NT, McBride JM. Acute effects of whole-body vibration on muscle activity, strength, and power. *J Strength Cond Res.* 2006;20:257-261.
11. de Ruiter CJ, van der Linden RM, van der Zijden MJA, Hollander AP, de Haan A. Short-term effects of whole-body vibration on maximal voluntary isometric knee extensor force and rate of rise. *Eur J Appl Physiol.* 2003;88:472-475.
12. Delecluse C, Roelants M, Verschueren S. Strength Increases after whole-body vibration compared with resistance training. *Med Sci Sports Exerc.* 2003;35:1033-1041.
13. de Ruiter CJ, van Raak SM, Schilperoort JV, Hollander AP, de Haan A. The effects of 11 weeks of whole body vibration training on jump height, contractile properties. *Eur J Appl Physiol.* 2003;90:595-600.
14. Rubin C, Turner AS, Bain S, Mallinckrodt C, McLeod K. Anabolism. Low mechanical signals strengthen long bones. *Nature.* 2001;412:603-604.
15. Rubin C, Xu G, Judex S. The anabolic activity of bone tissue, suppressed by disuse is normalized by brief exposure to extremely low-magnitude mechanical stimuli. *FASEB J.* 2001;15:2225-2229.
16. Bosco C, Iacovelli M, Tsarpela O, et al. Hormonal responses to whole-body vibration in men. *Eur J Appl Physiol.* 2000; 81:449-454.
17. Kerschan-Schindl K, Grampp S, Henk C, Resch H, et al. Whole-body vibration exercise leads to alterations in blood muscle volume. *Clin Physiol.* 2001;21:377-382.
18. Cardinale M, Ferrari M, Quaresima V. Gastrocnemius medialis and vastus lateralis oxygenation during whole-body vibration exercise. *Med Sci Sports Exerc.* 2007;39:694-700.
19. Sackett DL, Straus SE, Richardson WS, Rosenberg W, Haynes RB. *Evidence-Based Medicine: How to Practice and Teach EBM.* 2nd ed. Edinburgh, Scotland: Churchill-Livingstone; 2000:173-177.
20. Jadad AR, Moore RA, Carroll D et al. Assessing the quality of reports of randomized clinical trials: is blinding necessary? *Control Clin Trials.* 1996;17:1-12.]
21. 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 on nursing home residents. *Arch Phys Med Rehabil.* 2005;86:303-307.
22. Cheung W-H, Mok H-W, Qin L, et al. High-frequency whole-body vibration improves balancing ability in elderly women. *Arch Phys Med Rehabil.* 2007;88:852-857.
23. Gusi N, Raimundo A, Leal A. Low-frequency vibratory exercise reduces the risk of bone fracture more than walking: a randomized controlled trial. *BMC Musculoskelat Disord.* 2006 Nov 30;7:92.
24. Iwamoto J, Takeda T, Sato Y, Uzawa M. Effect of whole-body vibration on lumbar bone mineral density, bone turnover, and chronic back pain in post-menopausal osteoporotic women treated with alendronate. *Aging Clin Exp Res.* 2005;17:157-163.
25. Kawanabe K, Kawashima A, Sashimoto I, et al. Effect of whole-body vibration exercise and muscle strengthening, balance, and walking exercises on walking ability in the elderly. *Keio J Med.* 2007;56:28-33.
26. Russo CR, Lauretani F, Bandinelli S, et al. High-frequency vibration training increases muscle power in postmenopausal women. *Arch Phys Med Rehabil.* 2003;84:1854-1857.
27. Van Nes IJW, Latour H, Schils F, Meijer R, van Kuijk A, Geurts ACH. 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.
28. Bautmans I, van Hees E, Lemper J-C, Mets T. The feasibility of whole body vibration in institutionalized elderly persons and its influence on muscle performance, balance and mobility: a randomized controlled trial. *BMC Geriatrics.* 2005 Dec 22;5:17.
29. Bogaerts A, Delecluse C, Claessens AL, Coudyzer W, Boonen S, Verschueren SMP. Impact of whole-body vibration training versus fitness training on musle strength and muscle mass in older men; a 1-year randomized controlled trial. *J Gerontol.* 2007;62A:630-635.
30. Roelants M, Delecluse C, Verschueren SM. Whole-body-vibration training increases knee-extension strength and speed of movement in older women. *J Am Geriatr Soc.* 2004;52:901-908.
31. Verschueren SMP, Roelants M, Delecluse C, et al. 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.
32. Rubin C, Recker R, Cullen D, et al. 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.
33. Runge M, Rehfeld G, Resnicek E. Balance training and exercise in geriatric patients. *J Musculoskel Neuron Interact.* 2000;1:61-65.

34. Carmona R. Bone Health and Osteoporosis: A Report of the Surgeon General. US Health and Human Services; 2004.
35. Melton LJ. How many women have osteoporosis now? *J Bone Miner Res*. 1995;10:175-177.
36. Chevalley T, Guilley E, Herrmann FR, Hoffmeyer P, Rapin C-H, Rizzoli R. Incidence of hip fracture over a 10-year period (1991-2000): Reversal of a secular trend. *Bone*. 2007;40:1284-1289.
37. Hannan MT, Chen DM, Green E. Establishing the compliance in elderly women for use of a low level mechanical stress device in a clinical osteoporosis study. *Osteoporos Int*. 2004;15:918-926.
38. Rubin C, Judex S, QinY-X. Low-level mechanical signals and their potential as a non-pharmacological intervention for osteoporosis. *Age Ageing*. 2006;35-S2;ii32-ii36.
39. Conn VS, Minor MA, Burks KJ. Sedentary older women's limited experience with exercise. *J Community Health Nurs*. 2003;20:197-208.
40. Rasinaho M, Hirvensalo M, Leinonen R, Lintunen T, Rantanen T. Motives for and barriers to physical activity among older adults with mobility limitations. *J Aging Phys Act*. 2006;15:90-102.
41. Rubin C, Pope M, Fritton JC, Magnusson M, Hansson T, McLeod K. Transmissibility of 15-hertz to 35-hertz vibrations to the human hip and lumbar spine: determining the physiologic feasibility of delivering low-level anabolic mechanical stimuli to skeletal regions at greatest risk of fracture because of osteoporosis. *Spine*. 2003;28:2621-2627.
42. Liao S, Ferrell BA. Fatigue in an older population. *J Am Geriatr Soc*. 2000;48:426-430.
43. Abercromby AFJ, Amonette WE, Layne CS, McFarlin BK, Hinman MR, Paloski WH. Variation in neuromuscular responses during acute whole-body vibration exercise. *Med Sci Sports Exerc*. 2007;39:1642-1650.
44. Bovenzi M. Health effects of mechanical vibration. *G Ital Med Lav Ergon*. 2005;27:58-64.
45. Griffin MJ. *Handbook of Human Vibration*. Burlington, MA: Academic Press; 1996.
46. Lings S, Leboeuf-Yde C. Whole-body vibration and low back pain: a systematic, critical review of the epidemiological literature 1992-1999. *Int Arch Occup Environ Health*. 2000;73:290-297.
47. Seidel H. Selected health risks caused by long-term, whole-body vibration. *Am J Ind Med*. 1993;23:589-604.