WJO World Journal of Orthopedics

Online Submissions: http://www.wjgnet.com/2218-5836office
wjo@wjgnet.com
doi:10.5312/wjo.v1.i1.20

World J Orthop 2010 November 18; 1(1): 20-25
ISSN 2218-5836 (online)

REVIEW

Whole body vibration therapy in fracture prevention among adults with chronic disease

Marco YC Pang

Marco YC Pang, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong, China
Author contributions: Pang MYC was responsible for the review of the literature, and wrote the manuscript.
Correspondence to: Marco YC Pang, PhD, Associate Professor, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong, China. marco.pang@inet.polyu.edu.hk
Telephone: +852-27667156 Fax: +852-23308656
Received: October 11, 2010 Revised: November 5, 2010
Accepted: November 12, 2010
Published online: November 18, 2010

Abstract

Due to various physical impairments, individuals with chronic diseases often live a sedentary lifestyle, which leads to physical de-conditioning. The associated muscle weakness, functional decline and bone loss also render these individuals highly susceptible to falls and fragility fractures. There is an urgent need to search for safe and effective intervention strategies to prevent fragility fractures by modifying the fall-related risk factors and enhancing bone health. Whole body vibration (WBV) therapy has gained popularity in rehabilitation in recent years. In this type of treatment, mechanical vibration is delivered to the body while the individual is standing on an oscillating platform. As mechanical loading is one of the most powerful stimuli to induce osteogenesis, it is proposed that the mechanical stress applied to the human skeleton in WBV therapy might be beneficial for enhancing bone mass. Additionally, the vibratory signals also constitute a form of sensory stimulation and can induce reflex muscle activation, which could potentially induce therapeutic effects on muscle strength and important sensorimotor functions such as postural control. Increasing research evidence suggests that WBV is effective in enhancing hip bone mineral density, muscle strength and balance ability in elderly patients, and could have potential for individuals with chronic diseases, who often cannot tolerate vigorous impact or resistance exercise training. This article aims to discuss the potential role of WBV therapy in the prevention of fragility fractures among people with chronic diseases.

Key words: Falls; Vibration; Exercise; Rehabilitation; Balance; Bone density; Muscle

Peer reviewer: Karin Grävare Silbernagel, PT, ATC, PhD, Mechanical Engineering, Biomechanics and Movements Science, University of Delaware, Spencer Laboratory, Newark, DE 19716, United States

Pang MYC. Whole body vibration therapy in fracture prevention among adults with chronic disease. *World J Orthop* 2010; 1(1): 20-25 Available from: URL: http://www.wjgnet.com/2218-5836/full/v1/i1/20.htm DOI: http://dx.doi.org/10.5312/wjo.v1.i1.20

FRAGILITY FRACTURES AND CHRONIC CONDITIONS

Individuals with chronic diseases might sustain varying degrees of impairments in different body systems that considerably reduce their capacity to engage in physical activity, which gives rise to secondary bone loss[1]. Certain chronic diseases (e.g. stroke and multiple sclerosis) also directly impair muscle function. For example, muscle weakness or atrophy is a common manifestation among individuals with osteoarthritis and chronic obstructive pulmonary disease (COPD)[2,3], whereas spasticity is often observed in patients with stroke or multiple sclerosis[4,5]. As it is well known that muscle function is strongly correlated with the integrity of bone tissue[6-10], people with impaired muscle function are particularly prone to secondary osteoporosis.

In addition to the problem of secondary bone loss, people living with chronic diseases often have a number of fall-related risk factors, such as poor balance, compromised sensory function, impaired vision, and depression[11]. The combination of a sedentary lifestyle and impaired functional status could lead to further reduction in physical activity level, thereby triggering a vicious cycle of physical de-conditioning, bone loss, and falls. It is thus not surprising that individuals who live with chronic diseases often sustain an exaggerated fracture risk. For example, in stroke patients, a population that is known to have accelerated bone loss on the paretic side of the body[6,7,12,13] and elevated risk of accidental falls[14-17], the risk of fragility fractures is more than seven times higher within the first year post-stroke, when compared with people with no history of stroke[18]. At 8 years post-stroke, the excess risk of hip fracture remains 23% higher than in the reference population[18]. Among individuals with Parkinson's disease, another population that is highly susceptible to falls[19-24] and secondary osteoporosis[25-28], approximately 27% will sustain a hip fracture within 10 years of diagnosis, compared with only 9% among age-matched healthy subjects over the same follow-up period[29]. It is also worth mentioning that certain pharmacological agents used in patients with chronic diseases can exacerbate bone loss and increase the risk of fractures. One example is the long-term use of corticosteroids[30] in patients with advanced COPD[31] and rheumatoid arthritis[32]. Research has shown that corticosteroid treatment is associated with increased vertebral fracture risk in COPD patients[33,34].

Fragility fractures have become a major public health issue[35]. As the global population is rapidly aging, the number of individuals who live with chronic conditions, and hence the incidence of osteoporosis, falls and fragility fractures can only be projected to increase. Fragility fractures can lead to serious consequences, including increased morbidity, mortality, and health care costs[36-38]. The outcomes are even more unfavorable if fragility fracture is superimposed on a pre-existing chronic disease. Di Monaco *et al*[39] have demonstrated that patients with a chronic neurological disease (stroke or Parkinson's disease) have a significantly longer period of hospital stay after a hip fracture than their peers without a history of chronic neurological disease. It has also been shown by Ramnemark *et al*[40] that the 1-year mortality rate following a hip fracture is significantly higher among patients with a stroke history (29.3%) than those without (16.8%). Moreover, among the hip-fractured patients who were independent in mobility pre-admission, only 38% of those with a stroke history could regain independent mobility status upon discharge from the hospital, compared with 69% of patients without a stroke history[40].

In summary, patients living with chronic illnesses are highly susceptible to falls, bone loss and fragility fractures, which can lead to disabling, and sometimes fatal consequences. Hence, identifying effective intervention strategies to prevent or reduce fragility fractures through modification of fall-related risk factors and enhancement of bone health is of paramount clinical relevance.

WHOLE BODY VIBRATION: POTENTIAL APPLICATION IN PATIENTS WITH CHRONIC DISEASES

It has long been demonstrated that high-frequency mechanical stimuli can produce a strong osteogenic effect in animal models[41-45]. The encouraging findings from animal studies have raised the possibility that the dynamic mechanical stress involved in whole body vibration (WBV) therapy could be a viable method to enhance bone density in humans[46]. In WBV therapy, the individual is required to stand on an oscillating platform that is capable of generating mechanical vibration signals of varying frequency, magnitude, and duration. As the vibratory signals also constitute a form of sensory stimulation and can induce reflex muscle activation[47,48], WBV therapy is also proposed to have potential therapeutic effects on muscle strength and other important sensorimotor functions such as postural control[46].

Mounting research evidence has suggested that WBV therapy is an effective treatment method to improve bone health, and modify fall-related risk factors (e.g. muscle strength, and balance ability) in older adults. A number of randomized controlled studies have examined the effects of WBV therapy on hip and lumbar spine BMD in postmenopausal women[49-55]. A recent meta-analysis by Slatkovska *et al*[56] has shown that WBV has a small but significant effect on hip BMD in postmenopausal women. No overall significant effect on lumbar spine BMD, however, can be identified[56]. In addition to the reported positive outcomes on bone health, WBV has also been shown to have a significant effect on improving leg muscle strength and balance performance in several studies[49-51,54,57-68].

Patients living with chronic diseases could be potential beneficiaries of WBV therapy, considering that many of these individuals suffer from impaired muscle function, secondary osteoporosis, physical de-conditioning, and an elevated fracture risk. Research on the application of WBV in people with chronic diseases has flourished in recent years. The following section provides a summary of the findings on the effects of multiple sessions of WBV treatment in patients with chronic diseases. The WBV protocols employed in these studies are outlined in Table 1.

Chronic diseases that primarily affect the musculoskeletal system

A recent randomized controlled study has examined the effect of WBV therapy on muscle strength and proprioception in older women with knee osteoarthritis[69]. The subjects were randomly assigned to one of three groups: WBV exercise performed on a stable platform, WBV exercise performed on a balance board, and controls. After 8 wk training, those who underwent WBV exercise on a stable platform had significantly greater gain in isokinetic knee extension/flexion torque and isometric knee extension strength than control subjects. In contrast, those who underwent WBV training on a balance board had signifi-

Table 1 Application of whole body vibration therapy in chronic diseases: Protocol and results

Study	Chronic condition	Study design	Sample size	WBV protocol					Main results
				Frequency of vibration (Hz)	Amplitude of vibration (mm)	Duration of WBV exposure per day	Treatment days per week	Duration of program	
Trans *et al*[69], 2009	Osteoarthritis	RCT	52	24-30	Not reported	3-5 min	2	8 wk	WBV exercise on a stable platform resulted in significantly more gain in isokinetic knee extension/flexion torque and isometric knee extension strength than controls; WBV training on a balance board resulted in significantly more improvement in knee proprioception than controls
Ahlborg *et al*[70], 2006	Cerebral palsy	RCT	14	25-40	Not reported	6 min	3	8 wk	No significant difference in ambulatory and gross motor function outcomes between the WBV group and resistance training group
Wunderer *et al*[71], 2010	Multiple sclerosis	Single subject experimental design	3	40	2	30 min	2	6 wk	WBV resulted in increase in knee extensor muscle strength in all three subjects; WBV resulted in improvement in functional mobility (Timed Up and Go test) in two subjects
van Nes *et al*[72], 2006	Stroke	RCT	53	30	3	4 min	5	6 wk	Gains in balance, mobility and activities of daily living were comparable to that in the conventional exercise group
Ebersbach *et al*[73], 2008	Parkinson's disease	RCT	27	25	7-14	15 min/session, 2 sessions/d	5	3 wk	Gain in functional balance and gait velocity in WBV group was similar to those in the conventional physiotherapy group
Arias *et al*[74], 2009	Parkinson's disease	Non-randomized controlled trial	21	6	Not reported	5 min	2-3	5 wk	Balance and mobility outcomes after WBV exercise were similar to those after control exercises without WBV
Baum *et al*[75], 2007	Type Ⅱ diabetes	RCT	40	30-35	2	4 min	3	12 wk	No significant difference in maximal isometric torque of the quadriceps and fasting glucose concentration after treatment among the WBV group, the strength training group and the flexibility training group
Roth *et al*[76], 2008	Cystic fibrosis	Quasi-experimental (no control group)	11	12-26	7.8	6 min	3-5	6 mo	WBV resulted in no significant changes in the trabecular bone density of the tibia or spine; WBV induced an increase in explosive leg muscle strength
Rietschel *et al*[77], 2008	Cystic fibrosis	Quasi-experimental (no control group)	10	20-25	0.6	9 min/session, 2 sessions/d	5	3 mo	WBV induced significant improvement in performance in the chair-rising test and the two-leg jump test

RCT: Randomized controlled trial; WBV: Whole body vibration.

cantly greater improvement in knee proprioception than the controls had[69]. However, it is unclear whether the reported benefits are related to the exercise itself or the addition of vibration during exercise.

Chronic diseases that primarily affect the neurological system

A number of studies have examined the effects of WBV therapy in adults with different types of chronic neurological diseases, including cerebral palsy[70], multiple sclerosis[71], stroke[72] and Parkinson's disease[73,74]. In a small-scale study that involves 14 adults with cerebral palsy, Ahlborg *et al*[70] compared the effects of an 8-wk WBV program and a resistance training program. It was found that WBV was no better than resistance training in enhancing ambulatory function and gross motor skills. Using a single subject experimental design, Wunderer *et al*[71] examined the long-term effects of WBV in three patients with multiple sclerosis. Increase in knee extensor muscle strength was obtained in all three subjects, whereas improvement in mobility as measured by the Timed Up and Go test was observed in two of the subjects. Although this study suggests that the application of WBV in patients with multiple sclerosis has promise, further research using a randomized controlled design is required to establish the clinical efficacy of WBV in this patient group.

Other investigators have examined the effect of WBV in stroke patients. In a randomized controlled trial of 53 patients with subacute stroke, van Nes *et al*[72] have reported that their 6-wk WBV program has led to significant improvement in balance, mobility and activities of daily living that was comparable to that produced by the conventional exercise program. The effects of WBV on neuromuscular performance in patients with Parkinson's disease have also been examined by Ebersbach *et al*[73], who showed that their 3-wk WBV protocol did not result in significantly greater gains in functional balance and gait velocity compared with a control group who received conventional physiotherapy. In a non-randomized controlled trial, Arias *et al*[74] demonstrated that although improvement in balance and mobility were improved following 5 wk WBV, the treatment effect was similar to control exercises without vibration, which indicates that WBV has no additional effect in improving neuromuscular outcomes in Parkinson's disease patients.

Chronic diseases that primarily affect the respiratory and cardiovascular systems

Few studies have investigated the clinical efficacy of WBV therapy in chronic diseases that affect mainly the cardiovascular or respiratory systems. A randomized controlled study investigated the effects of a 12-wk WBV program in individuals with type Ⅱ diabetes[75]. The 40 subjects were randomly assigned to one of three groups: a WBV group, a strength training group, and a flexibility training group. The results showed no significant difference in maximal isometric torque of the quadriceps and fasting glucose concentration after treatment in the WBV group, the strength training group and the flexibility training group.

In contrast, Roth *et al*[76] examined the effect of WBV in adults with cystic fibrosis. The subjects received a home-based WBV exercise program for 6 mo, which resulted in no significant changes in the trabecular bone density of the tibia or spine. Improvements were observed, however, in explosive leg muscle strength, as measured by two-leg jump test (increase in muscle power and velocity) and one-leg jump test (increase in muscle force). The effects of WBV in patients with cystic fibrosis were also studied by Rietschel *et al*[77]. In their pilot study of 10 subjects with cystic fibrosis[76], it was found that the 3-mo WBV training program resulted in significant improvement in performance in the chair-rising test (reduced time, increased maximal force, maximal power and velocity) and the two-leg jump test (increased force and velocity). However, these studies did not have a control group, and therefore the interpretation of results warrants caution.

In summary, based on the available research data thus far, there is no evidence to suggest that WBV is superior to other exercise approaches in improving various neuromuscular outcomes in adults with chronic disease. This is in contrast to a good number of WBV studies in the general older adult population that have demonstrated the positive effects of WBV on balance performance and leg muscle strength[49-51,54,57-68]. It is possible that WBV protocols used in the general older adult population are not the optimal for inducing a therapeutic effect on the various outcomes of interest in patients with chronic disease. Perhaps a greater intensity and longer duration of training is required to obtain a significant treatment effect among patients with disabilities. It is also possible the non-significant results were partly due to the fact that small sample sizes were used, which had low statistical power. It would thus be difficult to detect a statistically significant difference, even if a true treatment effect existed. Surprisingly, despite the fact that bone health is a major health issue among patients with chronic disease, only one study has incorporated bone mineral density as the outcome[76]. There is a need for more research in this important area.

Adverse events

Similar to studies in older adults and postmenopausal women, very few adverse effects have been reported in WBV studies in patients with chronic disease. There have been isolated cases of head discomfort and increased fatigue[76]. One patient with a history of arthropathy developed joint effusion, but the symptoms subsided as training progressed[76]. One patient with cystic fibrosis and a history of venous thrombosis developed new thrombosis of the superior vena cava[75]. It is unclear how closely the adverse symptoms were monitored during the course of WBV therapy in these studies. It is also uncertain whether long-term adverse effects can result from WBV therapy. Based on the available data, however, WBV therapy seems to be a safe treatment technique when applied to individuals with chronic disease.

CONCLUSION

The research evidence on the clinical efficacy of WBV for improvement of bone health and modification of fall-related risk factors among patients with chronic disease is limited. Good quality randomized controlled trials are scarce. More research is needed to determine whether WBV therapy has a role in fracture prevention in individuals with chronic disease.

REFERENCES

1 **Uusi-Rasi K**, Sievänen H, Pasanen M, Oja P, Vuori I. Maintenance of body weight, physical activity and calcium intake helps preserve bone mass in elderly women. *Osteoporos Int* 2001; **12**: 373-379

2 **Palmieri-Smith RM**, Thomas AC, Karvonen-Gutierrez C, Sowers MF. Isometric quadriceps strength in women with mild, moderate, and severe knee osteoarthritis. *Am J Phys Med Rehabil* 2010; **89**: 541-548

3 **Wüst RC**, Degens H. Factors contributing to muscle wasting and dysfunction in COPD patients. *Int J Chron Obstruct Pul-*

mon Dis 2007; **2**: 289-300
4 **Sommerfeld DK**, Eek EU, Svensson AK, Holmqvist LW, von Arbin MH. Spasticity after stroke: its occurrence and association with motor impairments and activity limitations. *Stroke* 2004; **35**: 134-139
5 **Sosnoff JJ**, Shin S, Motl RW. Multiple sclerosis and postural control: the role of spasticity. *Arch Phys Med Rehabil* 2010; **91**: 93-99
6 **Pang MY**, Eng JJ, McKay HA, Dawson AS. Reduced hip bone mineral density is related to physical fitness and leg lean mass in ambulatory individuals with chronic stroke. *Osteoporos Int* 2005; **16**: 1769-1779
7 **Pang MY**, Eng JJ. Muscle strength is a determinant of bone mineral content in the hemiparetic upper extremity: implications for stroke rehabilitation. *Bone* 2005; **37**: 103-111
8 **Pang MY**, Mak MK. Trunk muscle strength, but not trunk rigidity, is independently associated with bone mineral density of the lumbar spine in patients with Parkinson's disease. *Mov Disord* 2009; **24**: 1176-1182
9 **Pang MY**, Mak MK. Muscle strength is significantly associated with hip bone mineral density in women with Parkinson's disease: a cross-sectional study. *J Rehabil Med* 2009; **41**: 223-230
10 **Madsen OR**, Sørensen OH, Egsmose C. Bone quality and bone mass as assessed by quantitative ultrasound and dual energy x ray absorptiometry in women with rheumatoid arthritis: relationship with quadriceps strength. *Ann Rheum Dis* 2002; **61**: 325-329
11 **Guideline for the prevention of falls in older persons**. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. *J Am Geriatr Soc* 2001; **49**: 664-672
12 **Jørgensen L**, Jacobsen BK. Changes in muscle mass, fat mass, and bone mineral content in the legs after stroke: a 1 year prospective study. *Bone* 2001; **28**: 655-659
13 **Ramnemark A**, Nyberg L, Lorentzon R, Olsson T, Gustafson Y. Hemiosteoporosis after severe stroke, independent of changes in body composition and weight. *Stroke* 1999; **30**: 755-760
14 **Tutuarima JA**, van der Meulen JH, de Haan RJ, van Straten A, Limburg M. Risk factors for falls of hospitalized stroke patients. *Stroke* 1997; **28**: 297-301
15 **Lamb SE**, Ferrucci L, Volapto S, Fried LP, Guralnik JM. Risk factors for falling in home-dwelling older women with stroke: the Women's Health and Aging Study. *Stroke* 2003; **34**: 494-501
16 **Jørgensen L**, Engstad T, Jacobsen BK. Higher incidence of falls in long-term stroke survivors than in population controls: depressive symptoms predict falls after stroke. *Stroke* 2002; **33**: 542-547
17 **Forster A**, Young J. Incidence and consequences of falls due to stroke: a systematic inquiry. *BMJ* 1995; **311**: 83-86
18 **Kanis J**, Oden A, Johnell O. Acute and long-term increase in fracture risk after hospitalization for stroke. *Stroke* 2001; **32**: 702-706
19 **Gray P**, Hildebrand K. Fall risk factors in Parkinson's disease. *J Neurosci Nurs* 2000; **32**: 222-228
20 **Fink HA**, Kuskowski MA, Orwoll ES, Cauley JA, Ensrud KE. Association between Parkinson's disease and low bone density and falls in older men: the osteoporotic fractures in men study. *J Am Geriatr Soc* 2005; **53**: 1559-1564
21 **Bloem BR**, Grimbergen YA, Cramer M, Willemsen M, Zwinderman AH. Prospective assessment of falls in Parkinson's disease. *J Neurol* 2001; **248**: 950-958
22 **Wood BH**, Bilclough JA, Bowron A, Walker RW. Incidence and prediction of falls in Parkinson's disease: a prospective multidisciplinary study. *J Neurol Neurosurg Psychiatry* 2002; **72**: 721-725
23 Mak MK, Pang MY. Balance confidence and functional mobility are independently associated with falls in people with Parkinson's disease. *J Neurol* 2009; **256**: 742-749
24 **Mak MK**, Pang MY. Fear of falling is independently associated with recurrent falls in patients with Parkinson's disease: a 1-year prospective study. *J Neurol* 2009; **256**: 1689-1695
25 **Wood B**, Walker R. Osteoporosis in Parkinson's disease. *Mov Disord* 2005; **20**: 1636-1640
26 **Sato Y**, Kaji M, Tsuru T, Oizumi K. Risk factors for hip fracture among elderly patients with Parkinson's disease. *J Neurol Sci* 2001; **182**: 89-93
27 **Di Monaco M**, Vallero F, Di Monaco R, Tappero R, Cavanna A. Bone mineral density in hip-fracture patients with Parkinson's disease: a case-control study. *Arch Phys Med Rehabil* 2006; **87**: 1459-1462
28 **Bezza A**, Ouzzif Z, Naji H, Achemlal L, Mounach A, Nouijai M, Bourazza A, Mossadeq R, El Maghraoui A. Prevalence and risk factors of osteoporosis in patients with Parkinson's disease. *Rheumatol Int* 2008; **28**: 1205-1209
29 **Johnell O**, Melton LJ 3rd, Atkinson EJ, O'Fallon WM, Kurland LT. Fracture risk in patients with parkinsonism: a population-based study in Olmsted County, Minnesota. *Age Ageing* 1992; **21**: 32-38
30 **Sambrook PN**. Glucocorticoid-induced osteoporosis. In: Favus MJ, ed. Primer on the metabolic bone diseases and disorders of mineral metabolism. Washington DC: American Society of Bone and Mineral Research, 2006: 296-302
31 **Maggi S**, Siviero P, Gonnelli S, Schiraldi C, Malavolta N, Nuti R, Crepaldi G. Osteoporosis risk in patients with chronic obstructive pulmonary disease: the EOLO study. *J Clin Densitom* 2009; **12**: 345-352
32 **Hall GM**, Spector TD, Griffin AJ, Jawad AS, Hall ML, Doyle DV. The effect of rheumatoid arthritis and steroid therapy on bone density in postmenopausal women. *Arthritis Rheum* 1993; **36**: 1510-1516
33 **Papaioannou A**, Parkinson W, Ferko N, Probyn L, Ioannidis G, Jurriaans E, Cox G, Cook RJ, Kumbhare D, Adachi JD. Prevalence of vertebral fractures among patients with chronic obstructive pulmonary disease in Canada. *Osteoporos Int* 2003; **14**: 913-917
34 **Nuti R**, Siviero P, Maggi S, Guglielmi G, Caffarelli C, Crepaldi G, Gonnelli S. Vertebral fractures in patients with chronic obstructive pulmonary disease: the EOLO Study. *Osteoporos Int* 2009; **20**: 989-998
35 **Johnell O**, Kanis JA. An estimate of the worldwide prevalence and disability associated with osteoporotic fractures. *Osteoporos Int* 2006; **17**: 1726-1733
36 **Kanis JA**, Oden A, Johnell O, De Laet C, Jonsson B, Oglesby AK. The components of excess mortality after hip fracture. *Bone* 2003; **32**: 468-473
37 **Kanis JA**, Johnell O. Requirements for DXA for the management of osteoporosis in Europe. *Osteoporos Int* 2005; **16**: 229-238
38 **Harvey N**, Earl S, Copper C. Epidemiology of osteoporotic fractures. In: Favus MJ, ed. Primer on the metabolic bone diseases and disorders of mineral metabolism. 6th ed. Washington DC: American Society of Bone and Mineral Research, 2006: 244-254
39 **Di Monaco M**, Vallero F, Di Monaco R, Mautino F, Cavanna A. Functional recovery and length of stay after hip fracture in patients with neurologic impairment. *Am J Phys Med Rehabil* 2003; **82**: 143-148; quiz 149-151, 157
40 **Ramnemark A**, Nilsson M, Borssén B, Gustafson Y. Stroke, a major and increasing risk factor for femoral neck fracture. *Stroke* 2000; **31**: 1572-1577
41 **Turner CH**, Robling AG. Designing exercise regimens to increase bone strength. *Exerc Sport Sci Rev* 2003; **31**: 45-50
42 **Robling AG**, Hinant FM, Burr DB, Turner CH. Improved bone structure and strength after long-term mechanical loading is greatest if loading is separated into short bouts. *J Bone Miner Res* 2002; **17**: 1545-1554
43 **Rubin C**, Turner AS, Müller R, Mittra E, McLeod K, Lin W, Qin YX. Quantity and quality of trabecular bone in the femur are enhanced by a strongly anabolic, noninvasive mechani-

cal intervention. *J Bone Miner Res* 2002; **17**: 349-357
44 **Flieger J**, Karachalios T, Khaldi L, Raptou P, Lyritis G. Mechanical stimulation in the form of vibration prevents postmenopausal bone loss in ovariectomized rats. *Calcif Tissue Int* 1998; **63**: 510-514
45 **Christiansen BA**, Silva MJ. The effect of varying magnitudes of whole-body vibration on several skeletal sites in mice. *Ann Biomed Eng* 2006; **34**: 1149-1156
46 **Rittweger J**. Vibration as an exercise modality: how it may work, and what its potential might be. *Eur J Appl Physiol* 2010; **108**: 877-904
47 **Cardinale M**, Lim J. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *J Strength Cond Res* 2003; **17**: 621-624
48 **Roelants M**, Verschueren SM, Delecluse C, Levin O, Stijnen V. Whole-body-vibration-induced increase in leg muscle activity during different squat exercises. *J Strength Cond Res* 2006; **20**: 124-129
49 **Russo CR**, Lauretani F, Bandinelli S, Bartali B, Cavazzini C, Guralnik JM, Ferrucci L. High-frequency vibration training increases muscle power in postmenopausal women. *Arch Phys Med Rehabil* 2003; **84**: 1854-1857
50 **Verschueren SM**, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. *J Bone Miner Res* 2004; **19**: 352-359
51 **Gusi N**, Raimundo A, Leal A. Low-frequency vibratory exercise reduces the risk of bone fracture more than walking: a randomized controlled trial. *BMC Musculoskelet Disord* 2006; **7**: 92
52 **Iwamoto J**, Otaka Y, Kudo K, Takeda T, Uzawa M, Hirabayashi K. Efficacy of training program for ambulatory competence in elderly women. *Keio J Med* 2004; **53**: 85-89
53 **Rubin C**, Recker R, Cullen D, Ryaby J, McCabe J, McLeod K. Prevention of postmenopausal bone loss by a low-magnitude, high-frequency mechanical stimuli: a clinical trial assessing compliance, efficacy, and safety. *J Bone Miner Res* 2004; **19**: 343-351
54 **Verschueren SM**, Bogaerts A, Delecluse C, Claessens AL, Haentjens P, Vanderschueren D, Boonen S. The effects of whole body vibration training and vitamin D supplementation on muscle strength, muscle mass and bone density in institutionalised elderly women - A 6-month randomised controlled trial. *J Bone Miner Res* 2010; Epub ahead of print
55 **von Stengel S**, Kemmler W, Engelke K, Kalender WA. Effects of whole body vibration on bone mineral density and falls: results of the randomized controlled ELVIS study with postmenopausal women. *Osteoporos Int* 2010; Epub ahead of print
56 **Slatkovska L**, Alibhai SM, Beyene J, Cheung AM. Effect of whole-body vibration on BMD: a systematic review and meta-analysis. *Osteoporos Int* 2010; **21**: 1969-1980
57 **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
58 **Rees SS**, Murphy AJ, Watsford ML. Effects of whole-body vibration exercise on lower-extremity muscle strength and power in an older population: a randomized clinical trial. *Phys Ther* 2008; **88**: 462-470
59 **Bautmans I**, Van Hees E, Lemper JC, Mets T. The feasibility of Whole Body Vibration in institutionalised elderly persons and its influence on muscle performance, balance and mobility: a randomised controlled trial [ISRCTN62535013]. *BMC Geriatr* 2005; **5**: 17
60 **Bruyere O**, Wuidart MA, Di Palma E, Gourlay M, Ethgen O, Richy F, Reginster JY. Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. *Arch Phys Med Rehabil* 2005; **86**: 303-307
61 **Bogaerts A**, Delecluse C, Claessens AL, Coudyzer W, Boonen S, Verschueren SM. Impact of whole-body vibration training versus fitness training on muscle strength and muscle mass in older men: a 1-year randomized controlled trial. *J Gerontol A Biol Sci Med Sci* 2007; **62**: 630-635
62 **Bogaerts AC**, Delecluse C, Claessens AL, Troosters T, Boonen S, Verschueren SM. Effects of whole body vibration training on cardiorespiratory fitness and muscle strength in older individuals (a 1-year randomised controlled trial). *Age Ageing* 2009; **38**: 448-454
63 **Raimundo AM**, Gusi N, Tomas-Carus P. Fitness efficacy of vibratory exercise compared to walking in postmenopausal women. *Eur J Appl Physiol* 2009; **106**: 741-748
64 **Furness TP**, Maschette WE. Influence of whole body vibration platform frequency on neuromuscular performance of community-dwelling older adults. *J Strength Cond Res* 2009; **23**: 1508-1513
65 **Machado A**, García-López D, González-Gallego J, Garatachea N. Whole-body vibration training increases muscle strength and mass in older women: a randomized-controlled trial. *Scand J Med Sci Sports* 2010; **20**: 200-207
66 **Cheung WH**, Mok HW, Qin L, Sze PC, Lee KM, Leung KS. High-frequency whole-body vibration improves balancing ability in elderly women. *Arch Phys Med Rehabil* 2007; **88**: 852-857
67 **von Stengel S**, Kemmler W, Engelke K, Kalender WA. Effect of whole-body vibration on neuromuscular performance and body composition for females 65 years and older: a randomized-controlled trial. *Scand J Med Sci Sports* 2010; Epub ahead of print
68 **Furness TP**, Maschette WE, Lorenzen C, Naughton GA, Williams MD. Efficacy of a whole-body vibration intervention on functional performance of community-dwelling older adults. *J Altern Complement Med* 2010; **16**: 795-797
69 **Trans T**, Aaboe J, Henriksen M, Christensen R, Bliddal H, Lund H. Effect of whole body vibration exercise on muscle strength and proprioception in females with knee osteoarthritis. *Knee* 2009; **16**: 256-261
70 **Ahlborg L**, Andersson C, Julin P. Whole-body vibration training compared with resistance training: effect on spasticity, muscle strength and motor performance in adults with cerebral palsy. *J Rehabil Med* 2006; **38**: 302-308
71 **Wunderer K**, Schabrun SM, Chipchase LS. Effects of whole body vibration on strength and functional mobility in multiple sclerosis. *Physiother Theory Pract* 2010; **26**: 374-384
72 **van Nes IJ**, Latour H, Schils F, Meijer R, van Kuijk A, Geurts AC. Long-term effects of 6-week whole-body vibration on balance recovery and activities of daily living in the postacute phase of stroke: a randomized, controlled trial. *Stroke* 2006; **37**: 2331-2335
73 **Ebersbach G**, Edler D, Kaufhold O, Wissel J. Whole body vibration versus conventional physiotherapy to improve balance and gait in Parkinson's disease. *Arch Phys Med Rehabil* 2008; **89**: 399-403
74 **Arias P**, Chouza M, Vivas J, Cudeiro J. Effect of whole body vibration in Parkinson's disease: a controlled study. *Mov Disord* 2009; **24**: 891-898
75 **Baum K**, Votteler T, Schiab J. Efficiency of vibration exercise for glycemic control in type 2 diabetes patients. *Int J Med Sci* 2007; **4**: 159-163
76 **Roth J**, Wust M, Rawer R, Schnabel D, Armbrecht G, Beller G, Rembitzki I, Wahn U, Felsenberg D, Staab D. Whole body vibration in cystic fibrosis--a pilot study. *J Musculoskelet Neuronal Interact* 2008; **8**: 179-187
77 **Rietschel E**, van Koningsbruggen S, Fricke O, Semler O, Schoenau E. Whole body vibration: a new therapeutic approach to improve muscle function in cystic fibrosis? *Int J Rehabil Res* 2008; **31**: 253-256

S- Editor Cheng JX **L- Editor** Kerr C **E- Editor** Lin YP