Review article

Clinical applications of vibration therapy in orthopaedic practice

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Summary

Background: **Vibration therapy (VT) has been proposed as an option to improve physical performance and reduce the negative effects of ageing on bone, muscles and tendons. Several discrepancies exist on the type of applications, frequency and magnitude. These differences reflex on the contradictory clinical results in literature. Aim of the present study is to carry on an exhaustive review to focus on technical options on the market, clinical applications in orthopaedic practice and expected outcomes.**
Methods: **a literature review using the key words "vibration therapy" and "whole-body vibration" and "orthopaedics" was performed. After checking the available abstracts 71 full text articles were evaluated.**
Results: **fifty-one articles focused on the effects of VT on muscles and tendons reporting ways of action and clinical outcomes. In a similar way 20 studies focused on the influence of VT on bone tissue with regard on ways of action and clinical trials.**
Conclusions: **VT provides anabolic mechanical signals to bone and musculo-tendinous system. The best effects seem to be achieved with devices that deliver low-intensity stimuli at high frequencies providing linear horizontal displacement.**

KEY WORDS: aged, athletes, electric stimulation therapy, osteoporosis, physical therapy modalities, rehabilitation.

Introduction

Disuse and aging are responsible for bone density decrease, loss of skeletal strength and muscle dysfunction. These effects may have severe impact on quality of life and social costs. In an opposite way it has been proven that bone and muscle tissues are influenced and respond to local dynamic loading[1]. This effect can be used to compensate the atrophy induced by disuse and aging or to improve bone and muscular function. The human body is daily exposed to relatively few low-frequency (1-3Hz), large-magnitude (2000-3000 microstrain) events but is subject to several high-frequency (10-50 Hz), low-magnitude signals (postural muscle contractions)[2]. Vibration therapy (VT) consisting of low-magnitude high-intensity (LIV) stimuli represents a good way to safely deliver relevant mechanical signals to patients who cannot exercise to build musculoskeletal strength[3]. Two wide categories of vibrating devices are actually available on the market: the so-called whole-body vibration (WBV) devices and vibration devices locally applied on a single muscle. Both are based on a mechanical stimulation characterized by frequency (in Hz) and amplitude of the oscillation induced (peak to peak displacement in mm) but they widely differ in terms of clinical applications. WBV applications have a vibration frequency in the range 20-50 Hz whereas local application to specific muscular district tolerates a much higher frequency range (around 300-500 Hz)[4]. Since the vibration can be applied with a wide spectrum of frequencies and settings[5] different effects on healthy and pathologic tissues are possible. Most common applications are: pain control[6,7], improvement of muscle force and flexibility[8], reduction of fatigue onset and accelerate rehabilitation[9-11] and increase bone density[12]. However only a few studies described specific vibrational training protocols, and this lack of information generates uncertainties regarding the most effective vibration intensities, frequencies, and application protocols. This reflects the wide controversy regarding expected outcomes. Aim of the present review is to analyze the available literature concerning vibration therapy with particular emphasis for its ways of action and clinical applications.

Materials and methods

A comprehensive literature review using the key-words "vibration therapy" and "whole-body vibration" and "orthopaedics" with no limit regarding the year of publication was performed. The following databases were accessed on 10 August 2015 PubMed (http://www.ncbi.nlm.nih.gov/sites/entrez/); Ovid (http://www.ovid.com); Cochrane Reviews (http://www.cochrane.org/reviews/), Google Scholar. 109 publications were identified. All the abstracts were reviewed by a single Author (SC). The full text papers were then selected or excluded according to the abstract text, excluding the article if an abstract was not available and the language was not English. In addition, the reference lists of the studies included were searched by hand to include articles not identified through the databases (n.56). At the end 71 articles were evaluated.
In accordance with international standards and as required by this Journal, Authors declare that the study meets the ethical standards of this Journal[13].

Results

Fifty-one articles focused on the effects of VT on muscles and tendons. Ways of action were thoroughly analyzed and explained in 16 studies while the outcomes of clinical trials were reported in 33 studies. They included results on healthy active subjects in 21 cases, elderly patients in 13 and children in 1. Twenty articles focused on the influence of VT on bone tissue with regard on ways of action and clinical trials. Seven studies investigated the possible mechanisms of action on bone metabolism; 11 reported the effects of VT in postmenopausal subjects, whereas 2 articles focused on the effects in disabled osteopenic children.

Discussion

Muscle function

The applications of WBV on muscle mass and function in trained athletes have been widely investigated in the past years[14,15] whereas the effects of local vibrations have received less attention. Vibrational stimuli (VS) have an important impact on muscle function both in young subjects and elderly patients.

Ways of action
VS can induce non-voluntary muscular contraction through the phenomenon of tonic vibration reflex (TVR)[16]. This is caused by the activation of the proprioceptive sensory system, which is based on the excitation of Ia afferent signals from the neuromuscular spindle (which respond to variations in length). These signals activate the a-motoneurons leading to recruitment of previously inactive muscle fibers[17]. Additionally VS, may also affect Golgi tendinous organs (GTO), which are sensitive to variation in tension[18]. Finally VS may inhibit the agonist-antagonist co-activation mediated by Ia-inhibitory neurons[19]. The final outcome is an increase in the contractive force of stimulated[20] and adjacent synergistic muscles[21]. Apart from the direct effect on muscle activation, VS seems to induce a stimulation of spinal and supraspinal functions, leading to better nervous control of muscular fiber recruitment[22]. This aspect has been confirmed by Iodice et al., who highlighted the role of sensory nervous system activation[23]. Local effects of VS such as muscle mass increase[24], or mechanical effects on muscle cross-bridges[25] are transitory and limited. Whereas according to the evidence of positive effects of proprioceptive training on muscle strength and function[26, 27], the main effect of VS could be related to a better central processing mechanism of afferent signals.
In addition it has been demonstrated that vibration enhances expression of anabolic genes in tendons [28]. Finally, part of the effect exerted by WBV on muscles and tendons could be related to variations in the endocrine system function. At this level it has been demonstrated an increase in the serum concentrations of growth hormone (GH) and testosterone, and a decrease in cortisol after WBV applications[15,20,23]. Variations in GH levels could be the consequence of increased gravitational loads produced by the vibrating platform[5].

Clinical applications: muscle training
Although it has been clearly demonstrated an effect of VS on muscle function, this widely changes according to the duration and intensity of application (Tab. 1). The effects of an acute application such as a single WBV session, include an increase in maximal muscle force, power output, and jump performance[20,29-31]. Conversely Rittweger et al. found a decrease in jump performance[32] and De Ruiter et al. reported a decline of 7% in the maximal isometric voluntary contraction (MVC) of the knee extensor muscles 90s after a single WBV training session[33].
Continuous application of WBV may indeed have negative effects rather than positive. Prolonged exposure seems to reduce muscle force and increase fatigue onset[7,34,35]. De Ruiter et al. reported the effects of 30 Hz WBV over a period of 11 weeks in young subjects stating that neither the strength nor the contractile properties of the knee extensor muscle improved[33]. Jackson et al. showed that prolonged exposition (30 min at 30 Hz) significantly attenuated muscle strength and EMG activity[36]. Conversely, some Authors reported positive effects[23, 37]. Iodice et al. reported that local application of high-frequency VS resulted in significant improvement of muscle performance after several weeks, however some hormonal variations and minor performance improvements were found after a single session[23].

Table 1. Clinical applications of WBV: muscle training.

Author	n. of patients	Type of vibration	Duration	Control group	Outcome
Bongiovanni 1990[7]	25	150 Hz	2 min	no	Depression of EMG activity
Bosco 1999[29]	12	30 Hz	5X1min	n.12 control group	Increased neural activity and muscle power
Issurin 1999[30]	28	44 Hz	6-7 sec	no	No increase in maximal and mean power
Bosco 2000[20]	14	26 Hz	10X1 min	no	Increased of T and GH, Decreased C
Rittweger 2000[32]	37	26Hz		no	Elicits a mild cardiovascular exertion
Torvinen 2002[31]	16	15-30 Hz	4 min	no	Transiently improves muscle performance
Jackson 2003[36]	10	30-120 Hz	30 min	no	Reduction in maximal force
De Ruiter 2003[33]	12	30 Hz	5X1 sec	no	No improvement in muscle activation
Mottram 2006[34]	n.25 suprathreshold	100 Hz	5 see	n.25 subthreshold n.25 control group	Reduced time to failure of a sustained contraction
Iodice 2011[23]	18	300 Hz	30 min	n.18 resistance program	Improved neuromuscular performance

C: cortisol
T: testosteron
G: growth hormone

Clinical applications: muscle soreness

Delayed-onset muscle soreness has been defined as disabling pain occurring 24-72 hours after unaccustomed or unfamiliar exercise. Several pathogenic theories have been proposed including connective tissue damage theory, muscle damage theory, inflammation theory and enzyme efflux theory. Some studies have investigated the role of WBV in the control of muscle soreness after physical activity (Tab. 2). In the majority of the cases WBV resulted in decreased DOMS and tightness and increased flexibility and muscle power when compared to control treatment[38-43]. Manimmanakorn et al. in a randomized study reported that WBV increased muscle oxygenation[44]. Wheeler et al. found no differences in terms of DOMS, muscle flexibility, or explosive power when WBV was compared to light exercise program[45]. In addition VS has proven to be effective on hamstring thightness as demonstrated in a recent review by Houston et al.[8].

Clinical applications: elderly patients

The normal senescence process affects the whole body with decrease of muscular performance, balancing ability and coordination and reduction of bone density. This process involves muscle composition and function, starting from the age of 30-40, with an increased loss after the age of 75. The isometric voluntary contraction decreases by 25% at age 65, and by 35% at the age of 70 years[46]. The sarcopenia has critical impact on the quality of life since it is cause of disability and weakness[47], with unstable balance, inability to ascend and descend stairs, or take the shopping bags home, all contributing to impairment of quality of life. Several methods have been proposed to attenuate this physiologic process including WBV (Tab. 3). Resistance training is an effective method to reduce the effects of sarcopenia. The effects of training programs on elderly subjects are comparable to those obtained in healthy adults. Frontera et al. showed an increase of the muscle mass and strength after 12 weeks of high intensity resistance training[48], with similar effects on elderly women. In a similar way, Pietrangelo et al. found increased muscle force, without signs of hypertrophy, in elderly subjects treated with HLV for 12 weeks[4]. Similar effects on muscular contractile properties in elderly have been widely reported in several clinical studies[49-51]. Other studies support that WBV has the potential to enhance the effects of physiscal training. Four months of high-intensity vibration (30-50 Hz, 2-2.8 g) combined with resistance exercises in postmenopausal women enhanced muscular strength compared with resistance training alone at multiple sites[52]. In a similar way Bogaerts et al. compared the outcomes of WBV in a group of elderly patients to those of fitness training and sham therapy[53]. WBV training resulted in an increase iso-

Table 2. Clinical applications of WBV: musclesoreness.

Author	n. of patients	Type of vibration	Duration	Control group	Outcome
Rhea 2009[38]	8	35 + 50 Hz	1min X2	n.8 control group	Reduced musclesoreness and tightness
Broadbent 2010 [41]	15	40 Hz	1 min X 3	n.14 Control group	Reduced musclesoreness and IL6 levels
Lau 2011[40]	15	65 Hz	30 min	n.15 control group	Decreased soreness
Aminian-Far 2011[39]	15	35 Hz	60 sec	n.17 control group	Reduced DOMS via muscle function improvement
Mohammadi 2012[42]	15	50 Hz	1 min	n.15 control group	Prevention of musclesoreness
Wheeler 2013[45]	10	30 Hz	10 min	n. 10 control group	No differences in DOMS, flexibility, or explosive power
Koh 2013[43]	20	20 Hz	10 min	n.20 ultrasound group n.20 control group	Decreased soreness
Manimmanakorn 2015[44]	8	30-40 Hz	10 min	n.8 active recovery	increased muscle oxygenation and blood flow

metric and explosive knee extension strength preventing the age-related loss in skeletal muscle mass. These effects on muscular performance have a dramatic influence on patient mobility and balancing ability. Bautmans et al. in a randomized controlled trial (RCT) on institutionalized elderly found that 6-week static WBV exercise was beneficial for mobility[54]. Cheung et al. reported WBV to be effective in improving the balancing ability in elderly women. In addition he found that a simple WBV treatment protocol of 3 minutes a day was effective to maintain balancing ability and reduce the risk of fall[55]. Wang et al. demonstrated that a 3-month program combining WBV and quadriceps strengthening exercise improved symptoms, physical function and spatiotemporal parameters in patients with medial compartment knee osteoarthritis[56]. Similar outcomes were reported by Rabini et al. who randomized 50 patients with knee osteoarthritis showing improvement in all functional parameters at 6 months FU[57]. Opposite results were reported by Segal et al. who investigated the effects of WBV platforms in a group of asymptomatic middle-aged women with risk factors for knee OA[58]. In this population, the addition of vibration to a 12-week exercise program did not result in significantly greater improvement in lower limb strength or power than did participation in the exercise program without vibration.

Clinical applications: children

Semler et al. evaluated the effects of high-intensity vibration (15-20 Hz, 1- 2 mm amplitude, ~12 g) combined with tilt-table exercise in a group of 8 children with osteogenesis imperfecta. After 6 months protocol significant improvements in muscle and ground reaction forces were observed[59].

Bone metabolism

Osteoporosis is a disease of the skeletal system characterized by low bone mass and deterioration of bone tissue[60]. Osteoporosis affects 2% of men and 10% of women over the age of 50 in the U.S.[61]. WBV in this field was initially proposed to reduce bone density loss of astronauts in space[62].

Ways of action

Several studies show that VS therapy improves bone circulation, increasing the supply of nutrients needed to build bones[31,63]. Vibration promotes osteogenic differentiation[64], cell communication[65], while reduces osteoclast formation[66] and expression of osteoclast-forming RANKL in osteocytes[67], which is increased during unloading[68].

Clinical applications: bone metabolism

A direct positive effect of WBV on calcium metabolism and bone mineral density (BMD) has been clear-

Table 3. Clinical applications of WBV: elderly patients.

Author	n. of patients	Type of vibration	Duration	Control group	Outcome
Roelants 2004[49]	89	Vibration platform	24 weeks	n.30 resistance-training group n.29 control group	Increased knee-extension strength and speed of movement
Verschueren 2004[51]	25	35-40 Hz	24 weeks	n.22 resistance-training group n.23 control group	Increased isometric and dynamic muscle strength
Bautmans 2005[54]	14	30-50 Hz	6 weeks	n.11 Control group	Increased leg extension Increased lower body flexibility
Roelants 2006[50]	15	35 Hz	Single session	No	Increased activation of leg muscles
Bogaerts 2007[53]	31	40-40 HZ	44 weeks	n.30 Fitness group n.36 Control group	Increased isometric muscle strength and muscle mass
Cheung 2007[55]	45	20 Hz	12 weeks	n.24 Control group	Increased stability, movement velocity, maximum point excursion, directional control
Pietrangelo 2009[4]	9	300 Hz	12 weeks	No	Increased maximal isometric strength No increase in muscle size Changes in gene exoression
Bemben 2010[52]	21	30-40 Hz	32 weeks	n.22 resistance-training group n.12 control group	Increate muscular strength Increased Hip adduction and abduction
Bellomo 2013[46]	10	300 Hz	12 weeks	n.10 Global Sensorimotor Training n.10 Resistance training n.10 Control group	Increased muscle strength
Segal 2013[58]	26	35 Hz	12 weeks	n.13 Exercise program	No significant improvement in lower limb strength or power
Wang 2015[56]	19	30Hz	16 weeks	n.19 quadriceps strengthening exercise	Improvement in physical function and spatio-temporal parameters
Rabini 2015[57]	25	100 Hz	24 weeks	n. 25 control group	Increased stability and balance

ly demonstrated (Tab. 4). Rubin et al. carried on a RCT comparing the effects of low intensity vibration (LIV) (10 minutes twice a day) with those of an inactive placebo plate in a group of postmenopausal women[69]. A decrease of 2% BMD was observed in the control group, whereas a 2.17% relative BMD increase was reported in the study group. Similar positive outcomes were reported with quantitative computed tomography[70]**.** An increase of 2% of trabecular and cortical bone was observed in those patients who received LIV compared with the inactive group. The major bias of the available literature on this specific issue is the low methodological quality and design of the studies. Most of them lack of control groups and widely differ in terms of intensity and duration of exposition to WBV. The effects of high-intensity vibration (30 Hz) for 10 min 5 days a week were investigated in a non-randomized controlled study on 116 postmenopausal women with osteoporosis[71]. An increase of lumbar and femoral neck BMD by 4.3 and

Table 4. Clinical applications of WBV: bone metabolism.

Author	n. of patients	Type of vibration	Duration	Control group	Outcome
Rubin 2004[69]	35	30 Hz vertical vibration	52 weeks	n.35 placebo	2.7% increase of BMD
Ward 2004[63]	10	90 Hz	24 weeks	n.10 placebo	6.3% increase of BMD
Gilsanz 2006[70]	24	30 Hz	24 weeks	n. 24 placebo	2.1 and 3.4% increase in lumbar and femoral BMD
Ruan 2008[71]	66	30Hz	24 weeks	n.50 placebo	3.2 and 4.3% increase in femoral neck and lumbar BMD
Slatkovska 2011[73]	67+68	30 Hz 90 Hz	52 weeks	n. 67 placebo	No increase in BMD
Von Stengel 2011 [75]	46	25-35 Hz	80 weeks	n.47 training group n. 48 placebo	No difference in BMD Reduced n. of falls
Von Stengel 2011 [76]	108 rotational vibration and vertical vibration	12.5 Hz rotational vibration 35 Hz vertical vibration	52 weeks	control group	Increased lumbar (0.5%) hip (0.3%) BMD and leg strength
Zha 2012[77]	34	45-55 Hz vertical vibration	24 weeks	n.33 placebo	Increase in BMD (especially in patients with osteoporosis)
Lai 2013[72]	14	30Hz	24 weeks	n.14 placebo	2% increase in lumbar BMD
Lam 2013[78]	61	32-37 Hz	52 weeks	n.63 placebo	increase in femoral neck and lumbar BMD
Gomez Cabello 2014[74]	24	35 Hz	11 weeks	n.25 placebo	No changes in DXA

3.2% was observed. In a similar study, the application of 30 Hz for 10 min thrice weekly, showed an increase of 2% of lumbar spine BMD at 6 months, whereas control subjects experienced BMD reduction[72]. Different results were observed in a randomized trial on 202 osteopenic postmenopausal women[73]. All patients received daily application of LIV (20 minutes) for 1 year, although in one group the intensity was 37 Hz and in the other it was 90 Hz No significant differences were found in the tibial trabecular BMD or femoral neck, total hip, or lumbar spine BMD. The major bias of this study was the low-compliance rate in the two groups (65-79%).

Several studies evaluated the effects of WBV in combination with dynamic exercise with contradictory results. Gomez-Cabello et al. in a randomized trial on 49 elderly subjects (either males or females) compared the outcomes of combined WBV (35Hz, ~16g) and trained squat three times a week for 11 weeks to a control group receiving no vibration or exercise program[74]. No changes in dual-energy X-ray absorptiometry scan measures were found. Von Stengel et al. carried on a 18-month randomized trial on 151 postmenopausal women study comparing the outcomes of conventional training program with conventional training program associated with WBV and with wellness control group[75]. Vibration therapy combined with low-impact activity enhanced the effect of training alone in increasing lumbar BMD. In addition subjects in the vibration group had decreased falls (probably as a consequence of better neuromuscular control). The same Authors compared the effects of rotational vibration training (RVT) (three sessions per week, for 15 min) associated with dynamic squat exercises, vertical vibration training (VVT) and a wellness control group (CG)[76]. One hundred-eight postmenopausal women were reviewed after 12 months. Increase in lumbar spine BMD and maximum leg strength was observed in both vibration VT groups compared to CG. Another study investigated the effects of a 6-month protocol consisting of WBV (44-55 Hz, 0.5 g) and alternative tilting performed three times per week[77]. Significantly BMD increases were reported in the study group that were higher in women compared with men, and in participants with osteoporosis, compared with those without low bone density.

In a similar way the effects of LIV on BMD have been studied in children with immobility-associated disability. Twenty disabled ambulant children were randomized to receive either LIV (90 Hz, 0.3 g, 10 min/day, 5 days per week) or placebo[63]. At 6 months subjects in the study group showed 6.3% increase in BMD, whereas those in the control group had a decrease of 12%. As reported in other studies the compliance rate was low (44%). The influence of WBV on BMD was assessed in 149 osteopenic children with idiopathic scoliosis[78]. Subjects in the study group had low-magnitude, high-frequency WBV (32-37 Hz, 0.3 g) for 20 min/day, 5 days weekly for 12 months. The treatment group showed significant increases in femoral neck BMD and an increase in lumbar spine bone compared with controls. These studies suggest that vibration has greater anabolic potential in the growing subjects probably influencing the activity of a more robust mesenchimal stem cells (MSC) pool.

Technical considerations

Although most of the studies show positive effects of vibration therapy on muscle function, physical performance, patient mobility and balancing and bone density, some series report contradictory outcomes. These wide differences may be the consequence of multiple devices used in clinical trials. These devices have different directionality (horizontal displacement, side-to-side or vertical), amplitudes (displacements resulting in gravitational force from less than 1 to greater than 15 g), and frequency (5-90 Hz)[79]**.** Some evidence suggests that muscle tension increases linearly with vibration frequency[17] and a 30-50 Hz frequency is appropriate[80]. On the contrary, there is no evidence that high-intensity vibration performs better than low-intensity vibration, and may lead to adverse effects. On the contrary in some cases, high-intensity vibration was responsible for muscle damage, back and joint pain[81]. The effects of frequency and intensity of the vibration are more important for local VS, than for WBV where the additional the changes in gravitational load play an additional role[5]. When selecting a treatment regimen, it is recommended to use devices that clearly report the vibration parameters and that deliver low-intensity (<1 g), horizontal displacements at high frequencies (30-100 Hz)[12].

Conclusion

Vibration therapy provides anabolic mechanical signals to bone and musculo-tendinous system. They mimic motion and exercise positively influencing muscle function and coordination. The influence on bone metabolism is achieved through mechanical regulation of mesenchymal stem cells, which provide progenitors for bone growth. Although no universal consensus exists on the ideal protocol to adopt, delivering low-magnitude high-intensity mechanical signals mimic the physiologic stimuli the human body has to deal with in daily life. This would ensure safe effects comparable to mild exercise programs.

Conflict of interests

The Authors declare that they have no conflict of interests regarding the publication of this paper.

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