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Original research

A customized low-magnitude vibration platform safely improves muscle strength, reduces bone turnover, preserves femoral bone density in postmenopausal women with osteopenia

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Abstract

Introduction: Osteoporosis is a disease that affects thousands of people worldwide. Prevention and treatment strategies are very important to reduce the incidence of falls and fractures in this population. **Objective:** evaluate the efficacy and safety of whole-body vibration (WBV) on bone mass, remodeling bone markers, muscle strength and pain points in osteopenic postmenopausal women using a custom low-intensity platform specifically designed for this study. **Methods:** Randomized controlled trial including 128 postmenopausal osteopenic women divided into two groups control (CG, n=60) and platform group (PG, n=68) that were created and assigned based on the block's allocation (by age and ethnicity). The participants in the platform group (PG) were assigned in blocks of 20 and committed to attending the research center five days a week, standing on the platform for 20 minutes each session. For every twenty participants in the PG, the next twenty were allocated to the control group (CG). Bone markers (P1NP and CTX) and thermometry were collected at baseline and at 3, 6, and 12 months. DXA scans performed at baseline and month 12 for bone mineral density (BMD) lumbar spine (LS), femoral neck (FN), and total hip (TH). The PG stood on vibrating platform (60 Hz, 0.6 g) for 20 min/day, 5 times/week for 12 months, while CG remained in their daily routine. Sit to stand test and pain points were evaluated at baseline and month 12. **Results:** 109 participants completed the 12 month-follow up (CG=55 and PG=54). At 12 months, the PG showed a significant decrease in BMD at FN (-0.8%, p=0.022) and TH (-0.9%, *p*=0.001), while BMD remained unchanged in the platform group, besides that the CTX significantly decreased at 3 months (*p*=0.006) and P1NP at 6 months (*p*=0.03), returning to baseline levels at 12 months, while there were no changes over time in the CG. Vibration improved the chair stand test by 15% (*p*=0.0001) and decreased pain points by 40% (*p*=0.001), with no increase in knee temperatures. **Conclusions:** Low-magnitude WBV prevented bone loss, improved physical performance, pain and was safe in postmenopausal osteopenic women.

Keywords: mechanical stimulation, bone turnover markers, low bone mass, prevention, sarcopenia, osteoporosis

1. Introduction

Falls and fractures are common occurrences among the elderly, contributing to high morbidity and mortality, particularly in postmenopausal women (1). Regular physical activity is a key to preventing these outcomes (2). However, maintaining the required intensity and load for such training can be challenging for this population. Emerging physical approaches, such as whole-body vibration, have been considered for the prevention of osteoporosis.

Bone cells seem to respond differently depending on the vibration frequencies and intensities. The vibration stimulus may stimulate bone remodeling by activating osteocytes, cells that act as mechanosensors that receive mechanical stimuli and convert them into biological signals that regulate bone remodeling, thereby improving bone quality (3,4). An experimental study with osteocytes that

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were stimulated low magnitude mechanical signals (0.3g and 20-90Hz) observed the decreased the Rank-L levels (reabsorption bone) especially at 60Hz (5).

Research in animals has demonstrated that vibration stimulus increases bone volume, number of trabeculae, bone density, and bone strength (6). In other investigations that also used a custom vibrating cage with low magnitude, (1-0.6g and 60 Hz) our group demonstrated the benefic effects of the vibration in animal models for glucocorticoid induced osteoporosis (7), for postmenopausal osteoporosis during estrogen replacement (8) and during treatment with teriparatide (9).

These positive results stimulated us to test this vibratory therapy in humans with risk for bone fragility. In humans, different clinical trials have shown diverse results of the effects of mechanical vibration on bone (10). Higher magnitudes along with exercises on the platforms are used to muscle training (11), but they are inappropriate for individuals with fracture risk.

We choose the magnitude 0.6 g because it can be likened to the force exerted during a vigorous walk or light jogging, corresponding to speeds of 7.2 to 9 km/h, thus providing a stimulus greater than that encountered in everyday activities and 60 Hz in attempt to enhance osteometabolic and muscular system, but without fatigue.

Based on previous research with low magnitude in vitro, in vivo, and human (12) to stimulate the musculoskeletal system against frailty without harm, we established the magnitude at 0.6g and a frequency of 60Hz and set the custom vibrating platform to investigate for 12 months the effects, efficacy, and safety of whole-body vibration (WBV) on musculoskeletal function in osteopenic postmenopausal women.

2. Methods

2.1 Ethics and device specifications

The custom vibration platform developed for this study used a Brazilian technology prototype designed and produced by the Department of Bioengineering of the School of Engineering at University of São Paulo, (USP) São Carlos (patent number BR 005204- March 03, 2019) with chosen vertical acceleration (0.6 g) and 60 Hz frequency.

This clinical trial was approved by the Ethics Committee of the Federal University of Sao Paulo (number 0318/08), and all participants completed an informed consent form. The study described has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans and followed the recommendations of the Consort statement.

2.2 Cohort

The participants were recruited through advertisements in the public media and in events organized for this purpose. Inclusion criteria were to be woman, ageing 55 or older, with at least 5 years of post-menopause. Exclusion criteria were to have osteoporosis or any other metabolic bone diseases, the use of medications interfering with bone metabolism (except for calcium and vitamin D), recent bone fracture, severe or acute osteoarthritis, knee or hip replacements, primary hyperparathyroidism, thyroid hormone abnormalities, rheumatoid arthritis, blood creatinine >1.4 mg/dL, alcoholism, uncontrolled hypertension, pacemaker, poorly controlled diabetes, severe neuromuscular diseases, and prolonged therapy with corticosteroids, bisphosphonates, estrogen, or selective estrogen receptor modulators.

We recruited 399 participants during screening, 264 fulfilled the inclusion criteria and underwent bone densitometry to assessment bone mass. The evaluation included bone sites such as the lumbar spine (LS), femoral neck (FN), and total hip (TH). Among these, 158 participants were observed to have a BMD indicative of osteopenia and were selected to clinical evaluation and family history including current use of medications and lifestyle, in addition to fasting blood drawing for biochemical measurements. We selected 128 postmenopausal women with osteopenia that fulfilled the inclusion and exclusion criteria. In order to ensure a well-balanced allocation of participants across study arms while mitigating potential biases, block randomization was employed in this trial. This method was selected to maintain equal group sizes throughout the enrollment period and to counteract any temporal or recruitment-related confounders that could arise in an open-ended sequential allocation process.

Two groups of participants were created and assigned based on the block's allocation (by age and ethnicity). The participants in the platform group (PG) were allocated (blocks of 20) and committed to attend the research center 5 days a week standing on the platforms for 20 minutes each session. For every twenty participants in the PG, the next twenty participants were allocated to the control group (CG). Thus, respecting the ages and ethnicities in blocks, allocations were finalized to make the groups as homogeneous as possible.

Baseline 25-hydroxyvitamin D levels were higher than 20 ng/mL in all participants; therefore, supplementation of this vitamin was not required.

2.3 Design

After the blocks selection the study began with CG 68 women (62.9 ±7.9 years) and PG 60 women (63.2 ±9.8 years). Under the supervision of a physiotherapist, they stayed barefoot and with extended legs on the vibrating platform, holding a support handle and without performing exercises (Figure 1) for 20 minutes, 5 days a week, for 12 months. All women in both groups had previously completed the International Physical Activity Questionnaire short version 20 (IPAQ). showing that the participants did not perform any type of muscle training before the study. Participants of both groups CG and PG came every 3 months to check for any adverse events, (PG) and to be sure that they did not modify their activities patterns. Adherence for the PG was measured by the frequency of vibration sessions. participants with a compliance rate < 80% and those who did not respond to, at least, two phone calls or did not undergo the last evaluation were excluded from the study. 19 participants [10 (16.6%) in the PG and 9 (13.2%) in the CG] dropped out of the study due to low compliance (n=8), family problems and change in work shift (n=6), pancreatitis (n=1), elective surgery (n=1), previous cardiac problem (n=1), renal lithiasis (n=1), and use of bisphosphonates 3 months prior the baseline (n=1). One hundred nine women completed the entire protocol, including 55 in the CG and 54 in the PG. (Figure 2).

All participants underwent bone densitometry, fasting blood draw, and physical and thermographic evaluation

Figure 1. Vibration platform prototype (A) and participants during a vibration session (B).

2.4 Bone densitometry

The recruited participants underwent bone densitometry (GE-Lunar DPX DXA System version: 11.40, GE Healthcare, Madison, WI, USA) for evaluation of the LS, FN, and TH BMD at baseline and after 12 months. The calculated minimum significant variation (MSV) was for LS =0.069 g/cm2, FN =0.055 g/cm2, and TH =0.092 g/cm2. The final selection included participants with osteopenia (T-score between -1.0 and -2.5).

2.5 Bone markers

Blood was collected after 8 hours of fasting (between 7 and 8 a.m.) at baseline and at 3, 6, and 12 months. Both turnover markers procollagen type 1 amino-terminal propeptide (P1NP) and carboxy-terminal cross-linking telopeptide of type 1 collagen (CTX) were measured using commercial kits (chemiluminescence, Elecsys 2010 analyzers; Roche Diagnostic, Indianapolis, IN, USA). Intra- and inter-assay coefficients of variation (CVs) were 1.8% and 2.7%, respectively, for P1NP and 4.6% and 4.7%, respectively, for CTX. PTH was measured by immunochemical assay (PTH- Elecsys 2010, Roche Diagnostics, Indianapolis, IN, USA), with intra- and inter-assay CVs of 3.0% and 3.5%, respectively.

2.6 Sit to stand test

The sit to stand test reckons the number of times an individual is able to get up from a chair with arms crossed over the trunk for 30 seconds and is used to evaluate the strength of the lower limbs, as well as the dynamic balance (13). The participants were assessed with this test at baseline and immediately at the end of the study.

2.7 Pain points

Each participant was asked to mark the location of her pain, when present, in an image of the human body silhouette (front and back) (14). The analysis considered the number of pain points at baseline and at the end of the study.

2.8 Thermographic assessment

Thermographic scanning was performed at baseline and at 3, 6, and 12 months to verify any damage to the knees caused by the mechanical vibration during the study, thus assessing the safety of the vibrating platform. Before the thermographic examination, a manual containing important directives was distributed to the participants. The evaluation was performed in a climate-controlled room, around 23.5 °C and relative humidity below 55%. The women were in the anatomical orthostatic position and their ear temperature was measured. A thermographic camera (Agema Thermovision 550, Sweden) was used to capture the infrared radiation emitted by the body and transforming it into temperature gradients. The colors images seen on the monitor were accompanied by a color palette that indicates the most heated by red and white colors, and the colder areas by blue and black colors. The calibration of the system was automatic. Regions of interest were defined in the central area of each thermographic image using circular outlines and the camera's software identifies the mean temperature in degrees Celsius (Figure 3). The difference between the right and left knees temperatures was used to identify a possible inflammatory process and it is considered clinically relevant if greater than 0.5°C. (15)

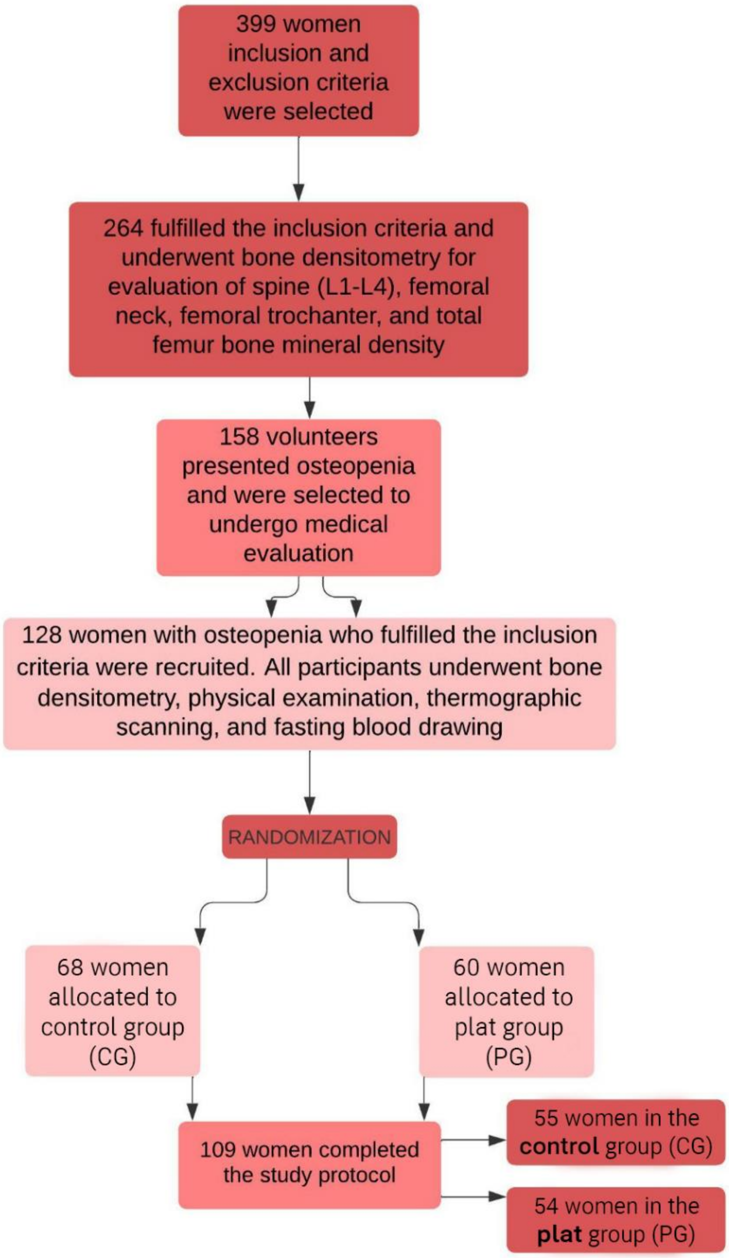

Figure 2. Study flow design.

2.9 Statistical analysis

The sample calculation was performed from Rubin et al. (6) using a vibrating platform in postmenopausal women with low bone mass, observing variance and with an effect- size of 80%. The Cohen index (Cohen´s d) was calculated to verify the clinical effect size in all study parameters. The statistical analyses were performed with the software package PASW Statistics for Windows, version 18.0 (SPSS Inc., Chicago, IL).

The data are presented as mean and standard deviation values, relative and absolute frequencies, and delta percentages (%). Kolmogorov-Smirnov test was used to verify the normality of the distributions. Also, Student's t test for dependent measures was applied to compare the results between groups, and Wilcoxon test for paired samples or the Mann-Whitney U test were employed for analyses of non-normal distributions. MANOVA was used to comparisons between both groups at different moments. Imputation method was applied for the missing data of all variables replacing missing values with the mean of the variables. Results were considered significant when $p \leq 0.05$. To ensure reliability, the data was performed in the generalized linear model.

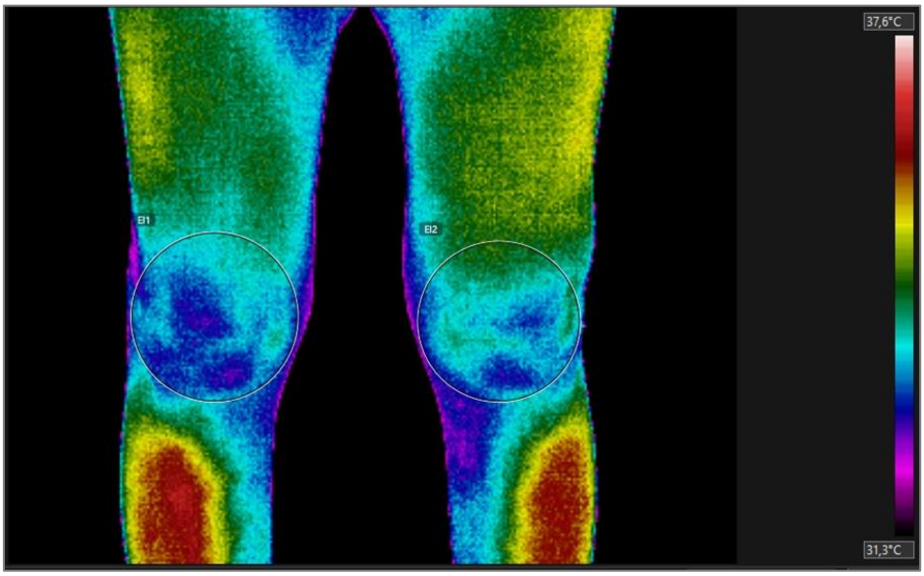

Figure 3. Example of an image of a normal thermographic evaluation of the knees in one of the participants, showing a selected region of interest. The figure shows a color palette that indicates the most heated by red and white colors, and the colder areas by blue and black colors. Regions of interest (the entire knees joint) were defined in of each thermographic image using circular outlines and the camera's software identifies the mean temperature (Celsius)

3. Results

One hundred and nine women completed the study (CG, n=55 and PG, n=54). Table 1 shows anthropometric and bone densitometric data at baseline and at 12 months in the CG and PG. At baseline, the total cohort had a mean age of 63.2±7.6 years (CG: 62.9±7.9 years and PG: 63.6±6.8 years, *p*=0.635), a BMI of 29.8±6.6 kg/m² and weight of 63.7±13.4 kg. All parameters were similar between both groups at baseline, except for the LS BMD, that was slightly higher in PG group. LS-BMD did not show significant changes (in the bone densitometric exam) in either group during the 12 months of the study. In the CG, there was a significant loss in femoral FN-BMD (-0.8%, *p*=0.002) and TH-BMD (-0.9%, *p*<0.0001) over the 12 months, while all parameters of the bone density remained unchanged in the PG over time.

Vibration induced a transient inhibition of bone turnover between the 3rd and the 6th months, which was demonstrated by the bone markers variation (Figure 4). The bone resorption marker CTX significantly decreased at 3 months (*p*=0.006) and P1NP at 6 months (*p*=0.03), both returning to baseline levels at 12 months and there was no change in these parameters in the CG group over time (Table 2, Figure 4). Levels of PTH unchanged over time in both groups.

Sit stand test improved by 15% (*p*=0.000) at 12 months in the PG (Figure 5), whereas no significant change was observed in the CG over time. The pain points in the PG decreased by 40% (*p*=0.001) in 12 months, while those in the CG showed no significant changes. There were no significant changes in the temperature of the knees measured by thermography in any group during the 12 months of the study (Table 2). No side effect related to the intervention were reported.

Table 1. Comparison of densitometric parameters at baseline and after 12 months.

	Control Group n=55		*Cohen's d*	*P*	Platform Group n=54		*Cohen's d*	*P*
	Baseline	**12 months**			**Baseline**	**12 months**		
Weight	67.3±9.6	66.8 ±10	0.05	0.682	63.9 ± 9.0	63.7± 9.3	*0.02*	0.604
IMC	28.4 ±5.7	27.2 ±7.7	0.17	0.188	27.0 ±3.7	27,0 ±3.6	0.00	0.706
Height	1.52±6.2	1.51±6.0	0.00	0.175	1.53±6.00	1.53±5.8	0.00	0.142
LS BMD	0.996±0.08	0.992±0.08	0.05	0.658	1.030±0.09*	1.024±0.10	0.06	0.265
LS T-Score	-1.460±0.71	-1.516 ±0.82	0.07	0.591	-1.230±0.79	-1.304±0.89	0.12	0.154
FN BMD	0.863±0.08	0.853±0.08	0.12	**0.022**	0.853±0.08	0.850±0.09	0.03	0.611
FN T-Score	-1.256±0.60	-1.340±0.61	0.13	**0.007**	-1.320±0.60	-1.370±0.65	0.07	0.091
TH BMD	0.939±0.08	0.926±0.08	0.16	**0.001**	0.911±0.15	0.920±0.28	0.04	0.566
TH T-Score	-0.570±0.60	-0.640±0.68	0.10	**0.031**	-0.610±0.75	-0.700±0.79	0.00	0.224

Note: Comparison of densitometric parameters at baseline and after months 12 BMD= bone mineral density, in g/cm2; LS= lumbar spine; FN= femoral neck; TH= total hip. The results are presented as mean ± standard deviation values. * Between groups at baseline (p=0.03).
*Cohen J. (1988) Statistical Power Analysis for the Behavioural Sciences. Second Edition. Lawrence Erlbaum Associates Publishers. Hillsdale New Jersey USA. ISBN 0-8058-0283-5. p. 407-410; 551.

Table 2. Comparison of bone markers and thermographic parameters in the control group and platform group at baseline and at 3, 6, and 12 months.

Variables	Gr	Baseline	3 months	ES* basal X 3m	6 months	ES basal X 6m	12 months	ES basal X 12m
P1NP (ng/mL)	**CG**	31.9± 30.3	47.8±12.7	**0.55**	43.5±15.8	**0.45**	52.6±14.3	**0.54**
	PG	44.8 ±26.2	44.8±19.1		**43.4±15.6****		**50.1±21.1*****	
CTX (ng/mL)	**CG**	0.377±0.19	0.297±0.22	0.02	0.335±0.27	**0.50**	0.352±0.14	-0.07
	PG	0.411±0.18	**0.326±0.23***		0.275±0.17		0.399±0.17	
PTH (pg/mL)	**CG**	56.3±19.0	50.6±22.9	-0.36	65.6±22.0	**0.53**	57.8±20.5	0.07
	PG	50.5±16.2	51.2±16.9		50.3±18.6		50.7±18.7	
TERMO (ºC)	**CG**	0.5±.4.6	0.5±.4.8	-0.02	0.7±.5.9	0.06	0.5±.4.4	0.02
	PG	0.6± 4.6	0.7±.5.1		0.5±.4.2		0.5±.4.1	

Note: The results are presented as mean±standard deviation values. p<0.05. *significant difference between baseline and 3 months p=0.006. **significant difference between 3 and 6 months p<0.05, *** significant difference between 3 and 12 months p=0.03. TERMO represents the differences of the temperatures measured in both knees. *Effect Size (ES) d_{ppc2} sensu
Morris S.B. Estimating effect sizes from pretest posttest-control group. Organization Research Methods 2008, 11:(2)364-386

4. Discussion

In postmenopausal women, the protocol involving vertical mechanical vibration at a frequency of 60 Hz, acceleration of 0.6 g, and displacement of < 0.4 mm preserved hip bone mineral density (BMD), a key predictor of fracture risk, while participants in the control group experienced bone loss at this site over time. It is important to note that the participants simply stood barefoot on the vibration platform with their legs extended for 20 minutes, without performing any additional exercises. Consistent with our findings, a review of 15 systematic reviews with meta-analyses on the effects of whole-body vibration (WBV) on bone density in postmenopausal women concluded that such vibration was insufficient to increase BMD. However, as observed in our study, there is evidence suggesting that WBV can help maintain BMD during this stage of a woman's life, when estrogen decline stimulates osteoclast activity, leading to bone resorption and increasing the risk of osteoporosis and fractures (16).

A reduction in bone resorption (CTX), followed by a decrease in bone formation (P1NP), led us to conclude that vibration suppressed bone remodeling from the outset, which may explain the maintenance of bone mass in this group. Similar reductions in bone resorption markers were observed by others following low-frequency (12 Hz) and low-magnitude (0.3 g) WBV in postmenopausal women (17). However, other studies reported no significant changes in bone remodeling markers, or even an increase in CTX, after 12 months of a high-magnitude vibration protocol (18). Nevertheless, a recent study employing this low-intensity mechanical signals demonstrated an increase in the cross-sectional area of the distal tibia in young women with anorexia nervosa, assessed by high-resolution peripheral quantitative tomography (19). These differences highlight that the effects of vibration can vary depending on the target population and the method used to evaluate bone structure.

Pharmacological strategies for preventing bone loss typically involve hormone replacement therapy or antiresorptive agents if necessary are indicated (1,20). Experimental studies from our group tested treatment with estrogen and teriparatide in ovariectomized rodents demonstrated an additive effect on bone mass when combined with WBV in these animals (8,9). In women, a randomized controlled trial comparing placebo with teriparatide alone or in combination with WBV (30 Hz, 1 mm displacement) for 6 months found a significant additional increase of 2.9% in BMD at the lumbar spine in the combined therapy group compared to teriparatide alone (21). These findings suggest that mechanical vibration may enhance treatment efficacy and improve patient compliance.

In the present study, the transient reduction in both bone resorption (CTX) and bone formation (P1NP) markers from the third month onward indicates a direct effect of vibration on bone remodeling. Bone remodeling markers are more sensitive than BMD to detect short-term systemic effects of physical interventions 2. Other studies have shown that exercise can lead to rapid changes in bone markers. For example, an increase in P1NP was observed after 6 months of high-intensity aquatic exercise in postmenopausal women, although BMD did not reveal any significant changes (22). However, the fact that both markers returned to baseline values by the end of this study suggests that an adaptation to the stimulus may have occurred over time, as seen in other physical exercise programs. A recent systematic review with meta-analysis of 40 studies examining the effects of WBV on bone density and remodeling markers in different populations concluded that WBV could have a positive clinical effect on bone metabolism and microstructure. However, due to significant variation in study designs, the authors could not identify an optimal vibration protocol for maximizing osteogenic effects (23).

Regular physical activity is crucial for enhancing muscle strength and balance, which are essential for preventing osteoporosis and sarcopenia (2,24). However, long-term engagement in exercise programs can be particularly challenging for certain groups, including postmenopausal women, the elderly, and individuals with co-morbidities that increase osteoporosis risk. This population often has limited capacity to participate in physical activities, making vibration therapy a viable and well-accepted alternative in such cases (25). In the current study, WBV led to a 15% improvement in the sit-to-stand test (bone fragility predictor and fall risk), likely due to increased lower limb strength and improved dynamic balance. The effects of mechanical vibration have shown robust results in enhancing muscle strength and physical function across various populations (23,25). Previously, we reported similar improvements in muscle strength of the hip flexors (36.7%), elbow flexors (22.8%), spinal extensors (36.5%), handgrip (4.4%), and balance (6.8%) after 12 months of WBV in postmenopausal women, with no changes observed in the control group26. Moreover, significant increases in flexibility, mobility, and agility were noted in the WBV group, despite the absence of exercises performed on the platform, suggesting potential benefits for preventing and even reversing aging-related sarcopenia.

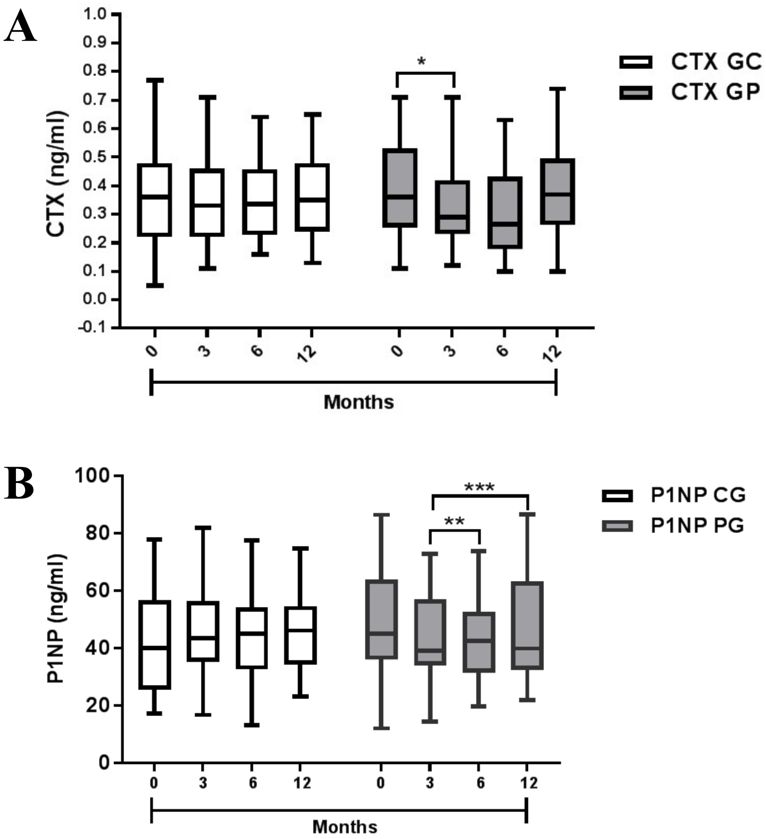

Figure 4. Variations in CTX (A) and P1NP (B) values at baseline and at 3, 6, and 12 months in the CG and PG group. The bone resorption marker CTX decreased in the PG. PG*0 months vs 3 months and remained unchanged in the CG. The bone formation maker P1NP increased in the PG. PG: **3 months vs. 6 months; *p*<0.05, *** significant difference between 3 months and 12 months, p=0.03. No significant differences were observed in the CG during the study.

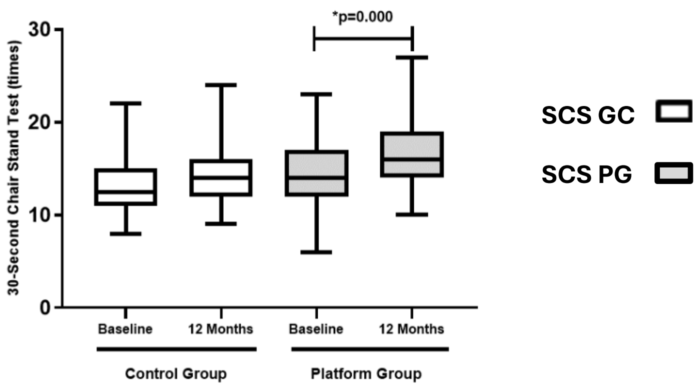

Figure 5. Sit to stand test at baseline and after 12 months in the CG and PG. There was a significant difference between baseline and 12 months in the PG, in which vibration increased the number of times the participants stood up from the chair in 30 seconds (p<0.001), while no difference was observed in the control group.

Furthermore, pain points decreased by 40% in the WBV group, while remaining unchanged in the control group. This reduction in pain could be related to isometric muscle contractions that release trophic and analgesic factors. A meta-analysis of 14 randomized controlled trials involving 559 patients with knee osteoarthritis (with durations ranging from 4 to 24 weeks) revealed that WBV, when combined with strengthening exercises, had significant beneficial effects on pain, physical function, and extensor isometric strength (28,29). Additionally, WBV once a week on a side-alternating platform (20 Hz, 0.7 to 4.2 mm displacement) was shown to reduce back pain in postmenopausal women with osteoporosis taking alendronate (29), although the parameters are different from those we use in our work. WBV induces muscle activity via stretch reflex mechanisms and the stimulus transmission can also occur through the fascial system 30. Studies have also demonstrated that WBV can alleviate muscle tension and improve circulation in individuals with chronic low back pain due to spinal disorders (25). Thus, the therapeutic effects of WBV on chronic back pain may result, in part, from reductions in muscle spasms, ischemia, and the clearance of fatigue-related metabolites.

Great caution is warranted when using high-intensity vibrations (>1.0 g), as they are associated with an increased risk of injury to multiple tissues and systems, particularly in frail and osteoporotic populations (31). A study with accelerometers evaluating the safety of vibration found that displacements greater than 0.5 mm can amplify acceleration and pose a risk to individuals with osteoarticular fragility (32). The low displacement (<0.4 mm) used in our study likely minimized the effect of foot-to-ground displacement, allowing us to isolate the mechanical vibration's effects from those induced by higher amplitude movements. Side effects were closely monitored throughout the study, with thermographic assessments conducted for three months to detect potential joint lesions, particularly in the knees. No significant temperature differences were observed between sides, indicating the absence of inflammatory reactions over the 12-month period. Moreover, participants reported no adverse effects during the study.

A limitation of this study is the absence of a sham platform, which could have helped control the placebo effect. Due to the limited number of available prototypes, the 12 platforms were installed in a single room, and participants assigned to the vibration group were divided into shifts to complete the 20-minute sessions five times per week. This setup made it challenging to implement and mask a sham group. On the other hand, the sessions were supervised daily by a physiotherapist throughout the study, providing greater control over participant adherence, side effects, and posture during the vibration sessions Despite the study's extended duration (5 sessions per week for 12 months) and the lack of financial incentives for participants, we achieved excellent adherence to the treatment protocol.

Conclusion

These findings, in conjunction with existing literature, indicate that low-intensity WBV can prevent bone loss associated with menopause, enhance muscle strength, and alleviate pain. Furthermore, combining vibration therapy with pharmacological treatments may enhance therapeutic effects without introducing additional side effects, offering a promising avenue for clinical practice. This custom vibratory platform was designed to deliver vertical oscillations at a frequency of 60 Hz, with an acceleration of 0.6 g and minimal displacement. It was specifically created to safely evaluate the effects of vibration therapy in osteopenic postmenopausal women. The present study demonstrated that a daily 20-minute vibration session, five times per week for 12 months, without physical exercise on the platform, effectively prevented bone loss in the proximal femur of postmenopausal women. Additionally, the observed transient reduction in bone turnover biomarkers suggested a systemic effect and likely a temporary suppression of bone resorption. Beyond assessing vibration safety, this study highlights that vibration therapy This study highlights that vibration therapy enhances lower limb strength and dynamic balance, which could be particularly valuable for improving mobility and preventing falls in postmenopausal women and other at-risk populations. For older adults, postmenopausal women, and individuals with comorbidities that increase osteoporosis risk, vibration therapy may serve as a viable and well-accepted alternative. It can encourage physical activity even outside the home, promoting mental well-being and improving the overall quality of life.

Conflict of interest

All authors of this manuscript declare that there is no conflict of interest in financial and personal relationships with any people, organizations, companies, laboratories or institutions.

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