High-Frequency Vibration Training Increases Muscle Power in Postmenopausal Women

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Objective: To test whether training on a high-frequency (28Hz) vibrating platform improves muscle power and bone characteristics in postmenopausal women.

Design: Randomized controlled trial with 6-month follow-up.

Setting: Outpatient clinic in a general hospital in Italy.

Participants: Twenty-nine postmenopausal women (intervention group, n=14; matched controls, n=15).

Intervention: Participants stood on a ground-based oscillating platform for three 2-minute sessions for a total of 6 minutes per training session, twice weekly for 6 months. The controls did not receive any training. Both groups were evaluated at baseline and after 6 months.

Main Outcome Measure: Muscle power, calculated from ground reaction forces produced by landing after jumping as high as possible on a forceplate, cortical bone density, and biomarkers of bone turnover.

Results: Over 6 months, muscle power improved by about 5% in women who received the intervention, and it remained unchanged in controls ($P=.004$). Muscle force remained stable in both the intervention and control groups. No significant changes were observed in bone characteristics.

Conclusion: Reflex muscular contractions induced by vibration training improve muscle power in postmenopausal women.

Key Words: Bone density; Exercise; Muscles; Postmenopause; Rehabilitation; Vibration; Women.

MUSCLE POWER, the capacity of muscles to produce work in the environment, declines significantly over the life span. In women, the rate of decline accelerates after menopause and leads to reduction in physical functioning.[1] It has been hypothesized that this process may be responsible for the development of physical frailty and mobility disability[1,2] in old age. Although evidence is overwhelming that physical exercise positively affects muscle strength at all ages, compliance of older persons with traditional exercise programs has generally been low, and only a small percentage of older persons exercise regularly.[3]

Vibration exercise on ground-based platforms that oscillate at high frequency has recently been proposed as an intervention for the prevention and the treatment of osteoporosis.[4-6] High-frequency (28Hz), very-low-magnitude (0.3*g*) vibration exercise has recently been reported to increase bone mass in experimental animals and in humans.[6-10] However, the mechanism by which vibrations influence the bone tissue remains unclear.[10]

The high-frequency postural displacements induced by the alternating movements of the platform produce reflex muscle contractions aimed at stabilizing posture.[11] Thus, vibration can be viewed as a special form of muscle training that may particularly affect muscle power.[12] It has been proposed that the force applied to bone during muscle contraction has a pivotal role in the homeostatic and adaptive regulation of bone strength.[13,14] This hypothesis may explain, in part, the mechanism by which vibration improves bone strength. To test this hypothesis, we conducted a small, randomized controlled trial (RCT) to discover whether training on a high-frequency vibrating board for 6 months would improve muscle power in postmenopausal women and, in turn, positively influence bone characteristics.

METHODS

Design

All the study procedures, including recruitment, measurements, and intervention, were performed in the Nuovo San Giovanni di Dio Hospital in Florence, Italy. The recruitment phase began in spring 1999 and was completed in fall 1999. The intervention began in the winter 1999–2000 and was completed by summer 2000. Among the 67 women belonging to a hospital volunteers association (Associazione Volontari Ospedalieri), 39 women who were at least 1 year postmenopausal and not affected by conditions that contraindicated the vibration training were enrolled in the study population (fig 1). Women on hormone replacement therapy were considered eligible. Women with metabolic bone disorders were excluded from the trial.

The screened women entered a 3-month run-in phase during which they received daily 1g of calcium carbonate and .25μg of activated vitamin D (calcitriol). This supplementation was administered to all the participants for the entire study period to avoid any influence of insufficient calcium or vitamin D intake on the effects of vibration exercise on bone apposition and mineralization. Because of the nature of the intervention, no blinding or placebo was considered. Of the 67 screened women, 33 agreed to participate in the study, signed an informed consent, and were randomized to either vibration or control group. A simple randomization procedure was applied using a series of random numbers. Six of the 39 eligible women

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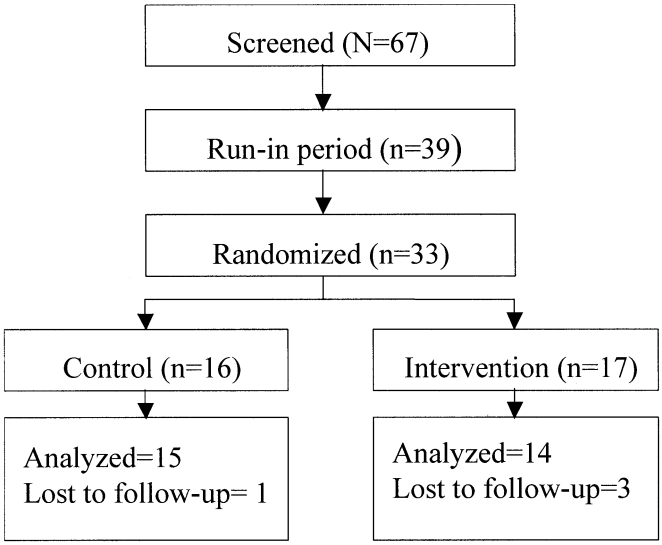

Fig 1. Flow diagram of the RCT.

refused to participate in the trial owing to family problems (n=2) and little interest (n=4).

Measurements

Blood and urine tests were performed to exclude from the trial subjects affected by metabolic bone disorders like primary hyperparathyroidism or hyperparathyroidism secondary to renal failure. All blood samples were drawn in the morning between 8:00 and 9:00 AM, in the fasting state. Routine biochemical parameters, which included total serum calcium, serum phosphorus, and creatinine, were measured using standard laboratory methods. Serum parathyroid hormone (PTH) was measured by a double-antibody chemoluminescence method[a] (interassay cell volume [CV]=2%), and serum bone-specific alkaline phosphatase was measured using an immunoenzymatic method[b] (interassay CV=5%). Deoxipiridinoline and *N*-terminal telopeptide were measured using a 1-step chemoluminescence method[a] (interassay CV=3%) and immunoenzyimatic method[c] (interassay CV=10%), respectively. To collect the 2-hour morning urine, participants were instructed to get up early in the morning and void. After 2 hours of fasting, during which only ingestion of water was allowed, participants voided again, and all urine samples were collected and used for measurements. To assess muscle power, participants, starting from a standstill, jumped as high as possible and landed on a forceplate[d] that measured ground reaction forces.[15] The best of 4 attempts was used in the analysis. The acceleration of the center of gravity (COG) was calculated as the ratio of force (N) and body mass (kg). The integration of acceleration by time gives the instantaneous velocity of the COG (m/s). The power (W) is obtained as the product of force and velocity. Tibial bone density, mass, and geometry were assessed by a recent generation, high-resolution, peripheral quantitative computed tomography device (XCT 2000[d]). Volumetric total bone density (mg/cm^3) was measured as the average density of the whole cross-section of the tibial metaphysis (4% of the tibial length from its distal end); that is, the section mainly composed of trabecular bone surrounded by a thin cortical shell. At the same site we assessed trabecular bone density (mg/cm^3) by excluding cortical bone. Measures of cortical bone density (mg/cm^3) and cross-sectional area (mm^2) were obtained from a cross-sectional image of the tibial diaphysis at 38% of the tibial length from its distal end. In these images, all of the voxels with a density above 710mg/cm^3 were considered to belong to cortical bone.

Intervention

The active intervention consisted of brief training sessions conducted twice weekly for 6 months. In each session, vibration was provided by a commercially available device (Galileo 2000[d]). By means of an oscillating board, this device delivers high-frequency vibration through the legs to the whole body. Participants stood with feet side by side on the board, which produced lateral oscillations of the whole body with accelerations in the range of 0.1 to 10*g*. At the beginning of the training, participants stood on the board with the knees slightly flexed and received three 1-minute bouts of vibration separated by 1-minute resting periods. During the first month of treatment, the frequency of vibration was progressively increased from 12 to 28Hz to allow for gentle adaptation. During the following 5 months of treatment, the frequency was always set at 28Hz, and the bouts of vibration were prolonged to 2 minutes. Participants were invited to separate the feet as far as tolerated to increase the amplitude and speed of the vertical displacement. Previous studies[11] have demonstrated that the oscillating movement of the board produces muscle stretching, which elicits alternating reflex contraction of the flexor and extensor leg muscle groups. Participants in the active group attended on average 34 sessions, corresponding to about 200 minutes of treatment, out of 44 sessions potentially available.

Statistical Analysis

All analyses were performed using the SAS, version 8.2, statistical software.[e] Data are reported as mean ± standard error (SE). Baseline characteristics of the intervention and control group were compared by 1-way analysis of variance (ANOVA). The magnitude of change over time in muscle and bone parameters in the intervention versus control group was compared using a repeated-measures ANOVA.

RESULTS

Women who received the active intervention were similar to controls in age, baseline muscle power, years since menopause, anthropometric measures, routine biochemical measurements, and biomarkers of bone turnover (table 1). Final measurement of the primary outcome (muscle power) was obtained in 29 of the 33 women who had been originally randomized (14 active treatment, 15 controls). Dropouts in the intervention group were caused by family problems (n=2) and knee pain (n=1). In 1 control, a measure of muscle power at the final follow-up could not be obtained because of posttraumatic muscle pain.

After 6 months, muscle power improved by about 5% (from 178.9±9.6W to 187.3±9.5W) in women who received the active treatment (table 2), whereas it declined slightly in controls. In a repeated-measure ANOVA, change over time in muscle power differed statistically between the 2 groups ($P<.02$). Overall, muscle power improved in 80% of the women in the treatment group and in 46% in the controls ($P=.06$). The velocity increased in the intervention group to a similar extent as the power (from 163.7±6.2m/s to 171.7±5.3m/s, $P<.005$), whereas muscle force did not change significantly in either group.

Cortical bone density remained stable in the intervention group, whereas it declined significantly in the control group ($P<.05$). However, in a repeated-measure ANOVA, the decline in cortical bone density over time did not differ statisti-

Table 1: Characteristics of the Participants at Baseline

Variable	Vibration Group (n=17)	Control Group (n=16)	*P*
Age (y)	60.7±6.1	61.40±7.30	.24
Height (cm)	159.2±5.4	160.2±7.50	.64
Weight (kg)	67.3±12.1	63.00±7.70	.24
BMI (kg/m^2)	26.2±4.6	24.20±3.30	.15
Years since menopause	11.2±6.0	11.30±6.70	.97
HRT use (no. of subjects)	4	4	
Biochemical measurements			
Creatinine (mg/dL)	0.9±0.1	1.1±0.2	.16
Serum calcium (mg/dL)	9.3±0.1	9.3±0.2	.75
Serum phosphorus (mg/dL)	4.4±0.1	3.6±0.3	.77
Bone alkaline phosphatase (μg/L)	18.6±4.5	16.0±3.6	.76
Serum PTH (pg/mL)	55.0±14.5	45.8±9.4	.33
Deoxipiridinoline (nm/L)	6.3±0.6	6.4±0.5	.70
N-terminal telopeptide (nm/L)	146.0±8.6	144.0±9.8	.61

NOTE. Values are mean ± SE.
Abbreviations: BMI, body mass index; HRT, hormone replacement therapy.

cally between the 2 groups ($P=.09$). All other bone parameters, including biochemical indices of bone turnover, did not change significantly during the study period in either group.

Transient, slight lower leg itching and erythema, a known side effect of the vibration exercise,[16] was also observed in 6 of 17 treated participants in this study. In no case, however, did this problem persist after the first 3 training sessions or cause interruption of the intervention. Knee pain of moderate intensity, without objective clinical signs, was observed in 2 overweight participants with preexisting knee osteoarthritis. The pain subsided in both participants after a few days of rest. One of them, however, refused to continue and was dropped from the study population.

DISCUSSION

In the present study, 200 minutes of high-frequency whole-body vibration, distributed in biweekly sessions over 6 months, improved muscle power and the velocity of movement in postmenopausal women without significant changes in muscle force. These results suggest that vibration training improves muscle power mainly by enhancing the pattern of recruitment of muscle fibers.

This study is the first to show an improvement of muscle power in postmenopausal women using vibration exercise. The decline in muscle power is an early and apparently inexorable occurrence in the life of a woman, perhaps contributing to physical frailty and mobility disability in late life.[2] Studies[17] have demonstrated that such a decline may be slowed by strength training exercise. However, the compliance of older persons in traditional exercise programs is poor.

High-frequency vibration on a ground-based platform stimulates continuously alternating reflex contractions of flexor and extensor muscle groups of the lower extremities.[11] We hypothesized that vibration is a special type of exercise that may be particularly suitable for older persons. It does not require much time or effort, does not cause potentially traumatic vertical displacements of the involved joints, and specifically trains type II muscle fibers, which are selectively lost during the aging process.[16,18] The availability of a simple, safe, and well-accepted training method that can improve muscle power in postmenopausal women opens a new perspective for the prevention of age-associated loss of muscle function in this group of women.

Previous studies have demonstrated that vibration exercise improves bone mineral density in animal and human models. Our findings provide a possible explanation for this effect of vibration exercise. Mechanical stress produced by muscle contraction plays a critical role in the maintenance of bone strength.[19,20] Thus, improvement in muscle force and power may be a strategy for improving bone characteristics and pre-

Table 2: Effect of 6 Months of High-Frequency Vibration Training on Muscle and Bone Parameters

	Control Group (mean ± SE)		Vibration Group (mean ± SE)		
	Baseline	After 6 Months	Baseline	After 6 Months	*P**
Starting participants (n)	16	15	17	14	
Dropouts (n)	0	1	0	3	
Muscle parameters*					
Force (N)	146.3±5.9	150.1±7.0	156.6±8.5	156.8±6.6	.60
Velocity (m/s)	178.1±4.8	175.5±4.1	163.7±6.2	171.7±5.3	<.005
Power (W)	179.9±7.5	179.1±7.8	178.9±9.6	187.3±9.5	<.02
Bone parameters†					
Trabecular volumetric bone density (mg/cm^3)	186.7±6.5	185.4±6.3	190.2±10.6	186.7±11.0	.70
Cortical volumetric bone density (mg/cm^3)	1100.9±8.6	1093.6±9.6	1101.7±9.3	1099.8±9.7	.09
Cortical bone area (mm^2)	239.9±8.2	240.7±8.3	246.4±11.2	242.5±11.6	.31

*Testing whether change over time in the specific parameter differed between groups.
†Mean values are calculated only with subjects who had valid measures both at baseline and at 6-month follow-up.

venting osteoporosis in postmenopausal women. In accordance with this hypothesis, our study showed that the decline in cortical bone density tended to be greater among control women than among women who received the active treatment. Our findings on cortical bone volumetric density are consistent with earlier reports[21] and support the hypothesis that vibration exercise may positively affect bone characteristics.[10] However, clinical trials that address these issues would require longer follow-up and, probably, a more intensive intervention. Based on earlier reports and on the present findings, our conclusion is that vibration exercise may be a more useful tool for the prevention and treatment of osteoporosis than pharmacologic treatment of osteoporosis,[22,23] a disease that is generally underdiagnosed and undertreated.[24,25]

The vibration training was safe overall. The only clinically significant side effect was knee pain, which was observed in 2 participants with preexisting osteoarthritis of the knee. This pain caused cessation of treatment in 1 subject. The frequent occurrence of transient lower leg erythema reported[16] previously was often observed in the present study, but it was always transient, mild, and not disturbing.

The present study has several limitations. First, the small number of participants and the relatively short duration of the intervention might have prevented us from identifying treatment effects on secondary outcomes such as muscle force or bone parameters. However, the effect on the primary outcome, muscle power, was small but clear-cut and therefore unlikely to be due to chance. Likewise, the treatment's safety clearly needs to be tested in larger studies. Second, the compliance with the treatment sessions was suboptimal; in fact, only 34 of 44 sessions were attended on average. However, an important reason for the low attendance was the restricted choice of days and time offered to the participants for the training sessions (because of our lack of financial resources). The training was perceived as very useful by the participants, who uniformly reported an improved well-being as a consequence of the training. Moreover, it can be considered a striking finding of this study that a substantial improvement in muscle power was obtained with only 200 minutes of training.

CONCLUSION

The results of this small RCT suggest that high-frequency vibration exercise is a feasible, safe, convenient, and efficacious intervention, which could prevent the decline in muscle and bone strength in postmenopausal women. Such intervention can easily be added as a component of an exercise-based prevention program or even prescribed as the sole intervention when traditional exercise is not feasible.

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