Effect of Whole-Body Vibration Exercise on Power Profile and Bone Mineral Density in Postmenopausal Women With Osteoporosis: A Randomized Controlled Trial

Abeer M. EIDeeb, PhD, and Amr A. Abdel-Azim, PhD

ABSTRACT

Objective: The purpose of this study was to investigate the effect of whole-body vibration (WBV) on muscle work and bone mineral density (BMD) of the lumbar vertebrae and femur in postmenopausal women.

Methods: Forty-three postmenopausal women with low BMD were randomly assigned to WBV and control groups. Both groups received calcium and vitamin D supplementations once daily, while the WBV group additionally received WBV exercise (twice/wk) for 24 successive weeks. Qualisys gait analysis system was used to measure hip power generation by hip extensors (H1S) and flexors (H3S), hip power absorption by hip flexors (H2S), knee power absorption by quadriceps during loading response (K1S) and preswing (K3S), knee power absorption by hamstring (K4S), knee power generation by quadriceps (K2S), ankle power absorption by dorsiflexors (A1S) and plantar flexors (A2S), and ankle power generation by plantar flexors (A3S). Also, dual-energy X-ray absorptiometry was used to measure BMD of the lumbar vertebrae and femur before and after the intervention.

Results: There were significant increases ($P < .05$) in the hip muscle work (H1S, H2S, and H3S), knee muscle work (K1S, K2S, K3S, and K4S), ankle muscle work (A1S, A2S, and A3S) during gait, and BMD of the lumbar vertebrae and femur of the WBV group. However, there were no significant changes ($P > .05$) in the control group. The posttreatment values of the hip, knee, and ankle muscle work and BMD of the WBV group were significantly ($P < .05$) higher than the posttreatment values of the control group.

Conclusion: Whole-body vibration training improved the leg muscle work and lumbar and femoral BMD in postmenopausal women with low BMD. (J Manipulative Physiol Ther 2020;43;384-393)

Key Indexing Terms: Bone Density; Gait analysis; Postmenopause; Osteoporosis; Vibration

INTRODUCTION

The whole-body vibration (WBV) training is an exercise program performed with the body on a vibration platform. These vibrations can stimulate the muscle spindles’ primary endings and thereby activate motor neurons, which cause muscle contraction, similar to the tonic vibration reflex. Therefore, WBV has positive effects on muscle performance.

Whole-body vibration may affect the levels of growth hormone, parathyroid hormone, and testosterone in serum, which may prevent sarcopenia and osteoporosis. Whole-body vibration exercise increases muscle strength and power that could lead to improvements in the quality of the neuromuscular functions. It reduces the rehabilitation time compared to other traditional resistance training programs. There are several intrinsic mechanisms of the mechanical vibrations that may be responsible for the prevention of loss, increase, or maintenance of bone mass. A previous study demonstrated that the loading frequency of WBV increased fluid flow in canaliculi.

The skeletal responses to WBV tend to be similar to those of exercise through the mechanotransduction process. The mechanical stimulation applied to the bone is detected by the cells that generate biochemical signals, stimulating osteogenesis. Whole-body vibration reduces bone loss in the lumbar spine and improves the hip bone mineral density (BMD) in postmenopausal women. Also, it has positive effects on leg muscle performance among untrained
people and older women. A recent study reported that WBV or pilates exercise performed for 6 months provided a similar effect on BMD in postmenopausal women.

Previous studies showed that lumbar spine BMD had a positive correlation with hip muscle torque in postmenopausal women. The maximum bench press and leg press were positive determinants of BMD in older women. Also, other studies reported an association between gait parameters and BMD. Low BMD was associated with a reduced dynamic hip range of motion and low hip extensor moments in the elderly. However, BMD was not significantly associated with hip joint moments during locomotion independent of body mass in healthy young women.

Despite WBV benefits on muscle strength, the efficacy of WBV on BMD and muscle work during gait in postmenopausal women is still uncertain. Marin and Rhea reported that WBV training could increase muscle strength, power, and jumping ability, with more improvements observed in untrained and elderly individuals. To the authors’ knowledge, there was no previous study that investigated the effect of WBV on gait parameters in postmenopausal women with low BMD.

Tang et al demonstrated the evidence that supports the use of calcium, or calcium in combination with vitamin D supplementation, in the preventive treatment of osteoporosis in people aged 50 years or older. They reported that the treatment reduced the rate of bone loss by 5.4% at the hip and 1.19% at the spine. Also, a previous review reported that vitamin D supplementation in a dose of 700 to 1000 IU per day reduced the risk of falling among older individuals by 1.19%. Moreover, another review demonstrated that a combination of calcium and vitamin D reduced the risk of falling more than vitamin D alone. However, other reviews concluded that taking calcium supplements showed small non-progressive increases in BMD, which did not induce a clinically significant reduction in the risk of fracture.

Based on the results of previous research, the purpose of this study was to find out whether there was a significant effect or not of adding WBV to calcium and vitamin D supplements on muscle work and BMD of the lumbar vertebrae and femur in postmenopausal women with low BMD. Therefore, the hypothesis was that the addition of WBV to medical treatment would improve lower-extremity muscle work and BMD of the lumbar vertebrae and femur more than medical treatment only in postmenopausal women with low BMD.

Methods

Participants

A physician recruited a total of 43 postmenopausal women and evaluated each woman for inclusion and exclusion criteria at the Nasser Institute Hospital for Research and Therapy. The participants’ ages ranged from 50 to 60 years, and body mass index was >25 kg/m² and <29.9 kg/m². They had natural menopause for 3 years or more. They experienced low BMD at the femoral neck (T-score < −1.0). The World Health Organization defined T-score as the number of the standard deviation above and below the mean BMD for healthy young adults. All participants were independent and did not engage in any treatment for osteoporosis for at least 6 months before enrollment in the study. The exclusion criteria were a history of diabetes, hypertension, kidney diseases, cardiopulmonary diseases, thrombosis, hyperprolactinemia, any medications or diseases that affect bone metabolism or neuromuscular performance, spondylothesis, back/leg deformities or surgeries, osteoarthritis, pacemakers, implants of the lower extremity and spine, tumors, migraines, or smoking. The demographic data of the participants are illustrated in Table 1.

The research design of this study was a randomized controlled trial. SPSS program version 16 randomly was used to assign the participants to 2 groups, which were the WBV and control groups. Enclosing the assignment in sequentially numbered, opaque, sealed envelopes was the method used for the allocation concealment. An external independent person performed the envelopes’ opening process in front of the participants. Based on a previous study, the sample size was calculated according to the mean value difference in the flexion variable between the control and the study groups. With an α of 0.05 (2-tailed), power of 80%, and an effect size of 0.91, a sample size of 20 patients per group would be required (G*Power 301, http://wwwpsycho.uni-duesseldorf.de). The study was performed following the Declaration of Helsinki and approved by the local institutional review board. Each participant signed a written consent form. The study has been registered (PACTR 201806003213442). The flow of the participants through the stages of the study is shown in Figure 1.

Table 1. Demographic Characteristics of the Participants

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Control Group, n=21</th>
<th>WBV Group, n=22</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>57.29 ± 4.44</td>
<td>55.09 ± 4.19</td>
<td>.103</td>
</tr>
<tr>
<td>Height, cm</td>
<td>158.86 ± 3.23</td>
<td>161.00 ± 3.84</td>
<td>.055</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>71.43 ± 5.42</td>
<td>73.55 ± 4.72</td>
<td>.179</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>28.28 ± 1.54</td>
<td>28.36 ± 1.31</td>
<td>.847</td>
</tr>
</tbody>
</table>

Data are presented as mean ± standard deviation. Significance (P < .05). BMI, body mass index; WBV, whole-body vibration.

Intervention

Both groups received calcium (1200 mg) and vitamin D (800 IU) once daily. Previous reviews concluded that the combination of both calcium and vitamin D was associated with a reduced rate of bone loss, and a reduced risk of
falls in the elderly. Also, the WBV group received WBV training twice per week for 24 weeks. All participants were instructed to maintain their normal daily living activities.

A whole-body vibration platform (DKN Pro, Hamme, Belgium) was used to apply training for the study group. The platform vibrated vertically at a frequency ranged from 20 to 35 Hz and amplitude ranged from 2.5 to 5 mm. Before starting the program, the researcher informed the participants about the WBV machine, the nature of training, and the benefits of vibration training to gain their cooperation during the study course.

Each participant stood on the vibrating platform with feet shoulder width apart, straight back, weight distributed equally on the balls of the feet, and hands on the machine’s railing for balance (Fig. 2). Then, the participant stood on the platform in various positions: half-squat, wide-stance squat, squat, deep squat, 1-legged squat, 1-legged stance, and lunge. In the half-squat, each participant placed both feet on the platform with knees slightly apart and flexed. In the wide-stance squat, the participant placed both feet on the edge of the platform with knees abducted and slightly flexed. In the squat position, both feet were placed in the middle of the platform with the knees bent 45° and back leaning slightly forward. In the deep squat, both feet were placed in the middle of the platform with the knees bent.

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**Fig 1.** Flowchart of the study processes. BMD, bone mineral density; WBV, whole body vibration.

**Fig 2.** Whole-body vibration training exercise.
90° and back slightly leaning forward. In the 1-legged squat, the participant stood with one knee slightly flexed, and the other knee was flexed 90° and was not on the machine. In the 1-legged stance, the participant stood with one knee extended, and the other knee was flexed 90° in front of the extended leg. In the lunge position, the participant stood on the platform with one hip and knee flexed to 90°, and the other hip and knee flexed and placed on the ground.25,26

Throughout the WBV program, raising the intensity of vibration or shortening the rest periods increased the training intensity. Also, increasing the duration of vibration sessions or the number of exercise repetitions increased the training volume. At the beginning of the training, the frequency of vibration was 20 Hz. It increased gradually to 25 Hz in the second month, 30 Hz in the third and fourth months, and finally 35 Hz in the fifth and sixth months. Throughout the treatment, the duration of the vibration exposure increased gradually from 5 to 10 minutes. The duration of each position was set at 30 seconds and increased to 45 seconds and 60 seconds. Rest periods between each position were 45 seconds in the third and fourth months, and finally 35 seconds in the fifth and sixth months.

Assessment Procedures

The lumbar and femur BMD and muscle work during gait were the outcomes evaluated before and after the intervention. For BMD measurements, the dual-energy X-ray absorptiometry (Unigramm X-ray Plus, IIb [93/42/CEE], UPG-00-174/01, Italy) was the method used to measure the BMD (g/cm²) of the lumbar vertebrae (L2-4), and femur (femoral neck, Ward’s triangle, and greater trochanter).

Qualisys gait analysis system (Qualisys Medical AB, Gothenburg, Sweden) is a valid and reliable tool used to assess gait parameters.28 It consisted of 6 cameras with the following characteristics: type170120, 100-240 V, 50-60 HZ, 230 mA, and 120 frames/s capture rate. It also had an AMTb Kistler force plate with an external amplifier type 9865, and a personal computer. The evaluator calibrated the cameras and force plate before measurement.

According to the system manual; the evaluator placed 20 reflective markers on the tip of each acromion, spinous process of 12th thoracic vertebrae, sacrum (between the right and left posterior superior iliac spine), each anterior superior iliac spine, greater trochanter, lateral side of the knee joint center, superior surface of the patella, tibial tuberosity, lateral malleolus, heel, and between the distal ends of the second and third metatarsals of feet.

For familiarization, the participants walked bare feet through the walkway several times to avoid the force plate targeting and gain high-quality data. Then, the evaluator adjusted the cameras on capturing mode, and each participant walked 3 trials at a self-selected speed. Finally, the evaluator identified all markers using Q Trac software, and exported and filtered the data using Q Gait software.

The data collected were the power profile of the right lower extremity in the sagittal plane. Eng and Winter described the muscle work during gait by 2 capital letters and 1 number. The first capital letter represents the joint (H = hip, K = knee, A = ankle), the number represents the power burst position, and the last capital letter represents the motion plane (S = sagittal). Table 2 illustrates the hip work profiles of the hip (H1S, H2S, and H3S), knee (K1S, K2S, K3S, and K4S), and ankle (A1S, A2S, and A3S) joints. H1S represents hip power generation by hip extensors during the loading response, H2S represents hip power absorption by hip flexors during the midstance, H3S represents hip power generation by hip flexors during the initial swing, K1S represents knee power absorption by quadriceps during the loading response, K2S represents knee power generation by quadriceps during the early midstance, K3S represents knee power absorption by quadriceps during the preswing, K4S represents knee power absorption by hamstring during the terminal swing, A1S represents ankle power absorption by dorsiflexors during the loading response, A2S represents ankle power absorption by plantar flexors during the midstance, and A3S represents ankle power generation by plantar flexors during the preswing.

Statistical Analysis

SPSS version 20.0 (IBM Corp, Armonk, New York) was used to analyze the collected data. The Shapiro-Wilk test of the outcome measures revealed that the data were normally distributed (P > .05). So, the parametric data analysis was the selected one. The paired t test was the test used to compare between pretreatment and posttreatment values of the measured outcomes of both groups. An independent t test was the test used to determine any significant difference in age, weight, height, or body mass index, and to compare between both groups before and after treatment. Percentages of change were also calculated. The least significant difference test was the test selected to locate the source of differences. The level of significance was less than .05.

RESULTS

There was no significant difference between both groups in age, height, weight, and body mass index (P = .103,
### Table 2. The Muscle Work (Watts/kg) of Lower Extremity Muscle Before and After the Intervention for Both Groups

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Control Group, n = 21</th>
<th>WBV Group, n = 22</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1S; concentric contraction of hip extensor</td>
<td>Pretreatment 0.57 ± 0.38</td>
<td>0.59 ± 0.36</td>
<td>.237</td>
</tr>
<tr>
<td></td>
<td>Posttreatment 0.58 ± 0.37</td>
<td>0.82 ± 0.37</td>
<td>.001*</td>
</tr>
<tr>
<td></td>
<td>P value .866</td>
<td>.042*</td>
<td></td>
</tr>
<tr>
<td>H2S; eccentric contraction of hip flexors</td>
<td>Pretreatment 0.28 ± 0.15</td>
<td>0.30 ± 0.16</td>
<td>.604</td>
</tr>
<tr>
<td></td>
<td>Posttreatment 0.29 ± 0.16</td>
<td>0.44 ± 0.28</td>
<td>.032</td>
</tr>
<tr>
<td></td>
<td>P value .090</td>
<td>.004*</td>
<td></td>
</tr>
<tr>
<td>H3S; concentric contraction of hip flexors</td>
<td>Pretreatment 0.52 ± 0.27</td>
<td>0.53 ± 0.33</td>
<td>.901</td>
</tr>
<tr>
<td></td>
<td>Posttreatment 0.53 ± 0.25</td>
<td>0.71 ± 0.30</td>
<td>.039</td>
</tr>
<tr>
<td></td>
<td>P value .400</td>
<td>.014*</td>
<td></td>
</tr>
<tr>
<td>K1S; eccentric contraction of quadriceps</td>
<td>Pretreatment 0.35 ± 0.13</td>
<td>0.41 ± 0.10</td>
<td>.71</td>
</tr>
<tr>
<td></td>
<td>Posttreatment 0.40 ± 0.16</td>
<td>0.51 ± 0.11</td>
<td>.009</td>
</tr>
<tr>
<td></td>
<td>P value 0.055</td>
<td>0.001*</td>
<td></td>
</tr>
<tr>
<td>K2S; concentric contraction of quadriceps</td>
<td>Pretreatment 0.36 ± 0.12</td>
<td>0.38 ± 0.18</td>
<td>.652</td>
</tr>
<tr>
<td></td>
<td>Posttreatment 0.38 ± 0.11</td>
<td>0.49 ± 0.20</td>
<td>.001*</td>
</tr>
<tr>
<td></td>
<td>P value 0.078</td>
<td>0.028*</td>
<td></td>
</tr>
<tr>
<td>K3S; eccentric contraction of quadriceps</td>
<td>Pretreatment 0.46 ± 0.21</td>
<td>0.52 ± 0.18</td>
<td>.351</td>
</tr>
<tr>
<td></td>
<td>Posttreatment 0.48 ± 0.22</td>
<td>0.67 ± 0.30</td>
<td>.024*</td>
</tr>
<tr>
<td></td>
<td>P value .397</td>
<td>.016*</td>
<td></td>
</tr>
<tr>
<td>K4S; eccentric contraction of hamstring</td>
<td>Pretreatment 0.68 ± 0.37</td>
<td>0.65 ± 0.35</td>
<td>.775</td>
</tr>
<tr>
<td></td>
<td>Posttreatment 0.69 ± 0.35</td>
<td>0.91 ± 0.32</td>
<td>.032*</td>
</tr>
<tr>
<td></td>
<td>P value .862</td>
<td>0.001*</td>
<td></td>
</tr>
<tr>
<td>A1S; eccentric contraction of dorsiflexors</td>
<td>Pretreatment 0.25 ± 0.19</td>
<td>0.22 ± 0.13</td>
<td>.480</td>
</tr>
<tr>
<td></td>
<td>Posttreatment 0.26 ± 0.11</td>
<td>0.34 ± 0.14</td>
<td>.039*</td>
</tr>
<tr>
<td></td>
<td>P value 0.054</td>
<td>0.001*</td>
<td></td>
</tr>
<tr>
<td>A2S; eccentric contraction of plantar-flexors</td>
<td>Pretreatment 0.92 ± 0.43</td>
<td>0.99 ± 0.44</td>
<td>.588</td>
</tr>
<tr>
<td></td>
<td>Posttreatment 0.93 ± 0.44</td>
<td>1.29 ± 0.62</td>
<td>.035*</td>
</tr>
<tr>
<td></td>
<td>P value .500</td>
<td>0.001*</td>
<td></td>
</tr>
<tr>
<td>A3S; concentric contraction of plantar-flexors</td>
<td>Pretreatment 1.94 ± 0.72</td>
<td>1.98 ± 0.79</td>
<td>.847</td>
</tr>
<tr>
<td></td>
<td>Posttreatment 2.01 ± 0.77</td>
<td>3.20 ± 1.13</td>
<td>.001*</td>
</tr>
<tr>
<td></td>
<td>P value .102</td>
<td>0.001*</td>
<td></td>
</tr>
</tbody>
</table>

Data are presented as mean ± standard deviation. The number indicates number of power burst. A, ankle; H, hip; K, knee; p, probability; S, sagittal; w, watt; WBV, whole-body vibration. * Significant (P < .05).
.055, .179, .847, respectively), as shown in Table 1. There was a significant increase in H1S, H2S, and H3S of the WBV group ($P = .042, .004, .001$, respectively) with a percentage of change equal to 37.44%, 47.51%, and 34.66%, respectively. However, there was no significant difference in the control group ($P = .866, .090, .400$, respectively) with a percentage of change equal to 1.22%, 5.05%, and 2.51%, respectively. The posttreatment values of the WBV group were significantly higher than the control group ($P = .001, .032, .039$, respectively). However, there was no significant difference between the pretreatment values of both groups ($P = .237, .604, .901$, respectively).

Table 2 illustrates the hip, knee, and ankle muscle work values.

There was a significant increase in K1S, K2S, K3S, and K4S of the WBV group ($P = .001, .028, .006, .001$, respectively) with a percentage of change equal to 23.97%, 29.24%, 29.04, and 39.97%, respectively. However, there was no significant difference in the control group ($P = .055, .078, .397, .862$, respectively) with a percentage of change equal to 13.83%, 5.54%, 4.53%, and 0.48%, respectively. The posttreatment values of the WBV group were significantly higher than the control group ($P = .009, .001, .024, .032$, respectively). There was no significant difference between the pretreatment values of both groups ($P = .071, .652, .351, .775$, respectively).

There was a significant increase in A1S, A2S, and A3S of the WBV group ($P = .001$) with a percentage of change equal to 55.91%, 30.11%, and 61.61%, respectively. However, there was no significant difference in the control group ($P = .054, .500, .102$, respectively) with a percentage of change equal to 4.42%, 1.30%, and 3.76%, respectively.

Regarding the BMD, there was a significant increase in the lumbar, femoral neck, Ward’s angle, and greater trochanter BMD of the WBV group ($P = .010, .001, .001, .001$, respectively) with a percentage of change equal to 8.55%, 8.02%, 26.67%, and 8.8%, respectively. However, there was no significant difference in the control group ($P = .089, .060, .773, .266$, respectively) with a percentage of change equal to 2.10%, 2.89%, 1.34%, and 1.72%, respectively. The posttreatment values of the WBV group were significantly higher than the control group ($P = .022, .010, .041, .032$, respectively). There was no significant difference between the pretreatment values of both groups ($P = .210, .118, .540, .477$, respectively), as shown in Table 3.

### DISCUSSION

The previous studies conducted on young participants reported that 6 weeks of WBV improved the maximal voluntary isometric and concentric muscle strength, respectively.

### Table 3. The BMD (g/cm²) Before and After Intervention for Both Groups

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Control Group, n = 21</th>
<th>WBV Group, n = 22</th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lumbar vertebrae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretreatment</td>
<td>0.90 ± 0.11</td>
<td>0.95 ± 0.11</td>
<td>.210</td>
</tr>
<tr>
<td>Posttreatment</td>
<td>0.92 ± 0.11</td>
<td>1.03 ± 0.17</td>
<td>.22</td>
</tr>
<tr>
<td>$P$ value</td>
<td>.089</td>
<td>.010</td>
<td></td>
</tr>
<tr>
<td>Femoral neck</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretreatment</td>
<td>0.62 ± 0.9</td>
<td>0.66 ± 0.06</td>
<td>.118</td>
</tr>
<tr>
<td>Posttreatment</td>
<td>0.64 ± 0.11</td>
<td>0.71 ± 0.07</td>
<td>.010</td>
</tr>
<tr>
<td>$P$ value</td>
<td>.060</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>Ward’s triangle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretreatment</td>
<td>0.52 ± 0.23</td>
<td>0.57 ± 0.27</td>
<td>.540</td>
</tr>
<tr>
<td>Posttreatment</td>
<td>0.53 ± 0.27</td>
<td>0.72 ± 0.33</td>
<td>.041</td>
</tr>
<tr>
<td>$P$ value</td>
<td>.773</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>Greater trochanter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretreatment</td>
<td>0.52 ± 0.11</td>
<td>0.55 ± 0.13</td>
<td>.477</td>
</tr>
<tr>
<td>Posttreatment</td>
<td>0.53 ± 0.09</td>
<td>0.60 ± 0.11</td>
<td>.032</td>
</tr>
<tr>
<td>$P$ value</td>
<td>.266</td>
<td>.001</td>
<td></td>
</tr>
</tbody>
</table>

Data are presented as mean ± standard deviation.

BMD, bone mineral density; $p$, probability; WBV, whole-body vibration.

* Significant at $P < .05$. 

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particularly for knee extensor muscles. Moreover, WBV induces a strength gain in knee extensors of untrained female adults. So, the novel aspect of this study was that it examined the effects of WBV training on the muscle work profile of the lower limb during gait in postmenopausal women with low BMD.

The present study revealed that the WBV group induced a significant improvement in the muscle contraction of the leg. The findings of the previous study supported these results, which indicated that the WBV training was efficient in enhancing the strength of the leg muscle and improving the functions of the lower limb muscle. Moreover, Verschueren et al. showed that vibration training improved the isometric and dynamic knee extensor strength in postmenopausal women with ages ranged from 58 to 74 years.

The present study showed an improvement in the eccentric contraction of the hamstring muscle. A previous study found that the short-term (up to 24 sessions or 2 months) side-to-side WBV training program improved the eccentric contraction of the knee flexors and failed to produce a similar effect on the concentric contraction of the knee extensors. The mode used in the current study was the vertical WBV. Thus, it was hard to compare the efficiency of the 2 vibration types directly. However, their result supported the current findings, especially that the side-to-side WBV could be less intense than the current intervention.

Bush et al. observed that the unilateral concentric knee extensor strength increased by 3.9% after vertical WBV sessions, which supported the significant improvement of the concentric contraction of the quadriceps. Moreover, Pollock et al. supported this finding; they showed that both increased motor unit recruitment and reduced recruitment thresholds of high threshold motor units occurred during WBV exercise. Also, Lienhard et al. reported that the lower limb muscles’ electromyographic activity increased during the vertical WBV training.

Many studies supported the current increase in quadriceps strength; Trans et al. and Tsuji et al. found a significant enhancement in quadriceps muscle strength following WBV exercise in women with knee pain. Also, Roelants et al. reported improvement in quadriceps muscle strength following WBV exercise in older women. Moreover, Osawa et al. reported additional gains in muscle strength following WBV training along with an exercise program in young and older individuals.

However, Liphardt et al. could not detect gains in muscle strength in postmenopausal women after 12 months of WBV training. Furthermore, 6 months of WBV training was not efficient in enhancing muscle mass and strength compared to vitamin D supplementation in women older than 70 years. So, the participants’ age may be the cause of controversy with the present findings.

The lack of muscle strength improvement of the control group is coincident with the findings of Suebthawinkul et al. They reported that after 12 weeks of vitamin D supplementation, there was no significant effect on the changes in muscle strength and mass compared to the placebo control group. Also, there were no differences in lean mass compared to the placebo group in overweight or obese postmenopausal women. Moreover, the leg strength reduced in the group that received vitamin D but not in the placebo group.

However, vitamin D supplementation with a higher dose (4000 IU/d) for 4 months had a modest beneficial effect on physical performance for frail individuals and those with insufficient vitamin D levels. Furthermore, there were significant increases in muscle strength after 9 months of vitamin D supplementation alone compared to the placebo group. The difference in the participants’ characteristics, vitamin D status, dose of vitamin D supplementations, and duration of the studies may explain the contradictions between the studies.

The recorded improvement of the hip muscle strength and BMD of the WBV group coincided with the findings of Zimmermann et al. They found that the strength of the hip adduction, knee extension, hip flexion, and grip force was associated with increased BMD of the L2-L4 vertebral bodies, greater trochanter, femoral neck, and Ward’s triangle. Also, they reported that strength could be a factor in the determination of BMD.

This study revealed that the WBV group showed significant increases in BMD of the lumbar vertebrae and femoral bone. The results agreed with the findings of Aloia et al., who showed that vitamin D supplementation in elderly black women did not prevent the bone loss, which may explain the lack of BMD improvement in the control group. Furthermore, the findings were consistent with recent systematic reviews, which concluded that taking calcium supplements produced small nonprogressive increases in BMD, which were unlikely to lead to a clinically significant reduction in the risk of fracture. However, they demonstrated that there might also be interactions between calcium intake and vitamin D status that need further exploration.

The improvement of the WBV group agreed with the findings of Von Stengel et al., who stated that WBV training was efficient in increasing the lumbar spine BMD. Also, the results of Lai et al. supported this finding; they found that 6 months of high-frequency and high-magnitude WBV yielded significant benefits to the BMD of the lumbar spine in postmenopausal women. Moreover, 8 months of WBV reduced bone loss at the hip and spine. Whole-body vibration is recommended as a potential therapy for individuals with osteoporosis.

However, WBV training exercise did not lead to improved bone quality in postmenopausal women with osteopenia, which was not coincident with the current results. Moreover, the addition of WBV to resistance training in postmenopausal women did not affect BMD. The inconsistency between studies may be due to the difference
in the WBV duration provided and the differences in the sample characteristics.

Limitations
The findings of this study are limited to the use of a vertical vibration platform mode; that is because most of the previous studies have reported an increase in the strength profile of knee extensors, as well as in vertical jumping performance. However, side-to-side vibration may induce a different degree of muscle stretch and tissue vibration on the leg muscle. This difference could lead to different neuromuscular responses compared to platforms using simultaneous vertical movement. So, comparing their effects on leg muscle profile and BMD in postmenopausal women is necessary.

Another limitation of this study was the assessment of leg muscle work (concentric and eccentric contraction) without considering isokinetic parameters such as power, work, and fatigue. Therefore, there is a necessity for more studies to investigate the effect of WBV training on these parameters. Moreover, there is a need for further research that investigates the impact of WBV without medical treatment on leg muscle work and BMD in postmenopausal women with low BMD considering the vitamin D status. Finally, there is a need for further research to evaluate the long-term effects of WBV training on functional outcomes.

Conclusion
This study found that 24 weeks of WBV training improved leg muscle work and increased lumbar and femoral BMD. Therefore, WBV may be considered in future research as an adjuvant method for preventing and rehabilitating postmenopausal women with low BMD to enhance the leg muscle power and BMD, which may, in turn, reduce the risk of falling and subsequent fractures.

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Concept development (provided idea for the research): A.M.E.
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Practical Applications
- This study showed that 24 weeks of whole-body vibration improved leg muscle work in postmenopausal women.
- This study showed that 24 weeks of whole-body vibration increased lumbar and femoral bone mineral density in postmenopausal women.

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