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Title: Effects of a 6-month local vibration training on bone density, muscle strength, muscle mass and physical performance in postmenopausal women

Running title: Local vibration in postmenopausal women

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ABSTRACT

The aim of the study was to investigate the effect of 6 months local vibration training on bone mineral density, muscle strength, muscle mass and physical performance in postmenopausal women (66–88 y). The study was organized as a randomized controlled trial for postmenopausal women who lived in daily care service flats and rest homes.

Thirty-five postmenopausal women were randomly assigned to either a vibration (n=17) or a control group (n=18). The vibration group received 6-month local vibration treatment with frequency between 30 and 45 Hz and acceleration between 1.71 and 3.58 *g*. The vibration was applied on the mid-thigh and around the hip in supine lying position once per day, 5 days/week. The participants of the control group continued their usual activities and were not involved in any additional training program. The primary outcome variables were the isometric and dynamic quadriceps muscle strength, and the bone mineral density of the hip. We assessed the muscle mass of the quadriceps and physical performance. Additionally, the feasibility, side effects and compliance were evaluated after 6 months of local vibration training. Overall, the results showed a net benefit of 13.84% in isometric muscle strength at 60° knee-angle in favor of the vibration group compared to controls (P<0.01). No changes in bone mineral density, muscle mass or physical performance were found in both groups (P>0.05).

Six months of local vibration training improved some aspects of muscle strength, but had no effect on bone mineral density, muscle mass and physical performance in postmenopausal women. The specific vibration protocol used in the present study can be considered as safe and suitable for a local vibration training program.

Key words: mechanical loading, tonic vibration reflex, safety.

INTRODUCTION

Aging is associated with a decrease in bone mineral density (BMD) known as osteoporosis, and a decline of lean muscle mass and muscle strength known as sarcopenia (21,36). Both osteoporosis and sarcopenia are important socio-economic and personal problems as they contribute to an increased fall risk, an increased number of hip and vertebral fractures, and physical weakness (7,29,32). Hip fractures are associated with high mortality and morbidity rate among postmenopausal women (6). Therefore, the prevention of bone loss and muscle weakness remains an important question.

Mechanical loading by means of physical exercise has been shown to have an osteogenic effect, to increase muscle strength and to improve body balance (15,18,19). High-impact exercises such as running and jumping may enhance bone acquisition in young age (1,14,25), and maintain bone mineral density, reduce the risk of falls and osteoporotic fractures at older ages (5,10,16,20,23,39). However, high-impact training is not practical and even unsafe in a significant proportion of older individuals, potentially leading to injuries and even fractures (9).

An alternative training method might be the vibration training which combines factors of both impact exercise and conventional resistance training. The effects of long-term whole-body vibration (WBV) training on BMD and muscle power have previously been reported among elderly (2,27,30,38). However, WBV may not be an adequate training method for a large segment of the adult's populations including frail elderly, adults that are in a wheelchair or bedridden individuals, and patients with knee osteoarthritis who are unable to stand on a whole-body vibration platform. These older adults have a high risk for osteoporosis and sarcopenia, thus, are at high risk for falls and fractures.

Therefore, a different form of vibration training – local vibration training was applied in an attempt to broaden the impact of vibration intervention to frail elderly. First, custom-made vibration devices were specially designed for this study in order to broaden the effect of vibration training to specific target body zones. Applying the vibration training locally may avoid the significant decrease of vibration signal up to the thigh and the hip (35), e.g. patients with knee prostheses. Second, we conducted a pilot randomized controlled trial for postmenopausal women who underwent 6 months of locally applied vibrations at the mid-thigh and around the hip. Effects of this locally applied vibration on static and dynamic knee muscle strength, muscle mass, and bone mineral density were assessed. Delivering the vibration locally at the regions which are most at risk for fractures (hip) or most in need of muscle strengthening (m. quadriceps) might be a more suitable approach than WBV training.

METHODS

Experimental Approach to the Problem

The study was designed as a randomized controlled trial for postmenopausal women who were randomly assigned to a vibration group (n=17) or a control group (n=18). The participants in the vibration group applied vibration locally with frequencies between 25 Hz and 45 Hz, and accelerations between 1.71 and 3.58 *g*. Muscle strength and muscle mass, bone density, and physical performance were assessed at baseline and after 6-month vibration intervention.

Subjects

Fifty postmenopausal women volunteered to participate in the study. The inclusion criteria were: (1) age above 65, (2) free from medications known to affect bone metabolism or muscle strength, (3) obtained approval following an extensive medical examination by a general practitioner, and (4) free from hip prosthesis. Participants were excluded if they met any of the following criteria: severe heart and vascular diseases or neurological disorders like Parkinson’s disease, multiple sclerosis, epilepsy and peripheral neuropathy. After an extensive medical screening 35 postmenopausal women met the inclusion and exclusion criteria and were included in the study. The participants were randomly assigned to a vibration group (n=17) or a control group (n=18) using computer-generated random numbers (Figure 1). None of the participants were engaged in another training program, or in regular organized sports or other physical activities. All participants gave written informed consent after receiving both verbal and written information about the study and its possible risks. The study was approved by the Leuven University Human Ethics Committee according to the declaration of Helsinki.

(Figure 1 about here)

Procedures

Vibration equipment

Custom-made vibration devices were specially designed for the current study (Fig. 2). Each device consisted of one control unit, four vibrators connected to the control unit and a medical approved power supplier (Powerbox, 24V – 2.9A, Gnesta, Sweden). Each vibrator had an encoder. The rotating element inside the vibrators was a cylindrical brass part with a diameter of 20 mm and a thickness of 8 mm (weight: 0.022 g). The frequency of the rotating element was continuously adjustable between 25 Hz and 45 Hz, which resulted in peak acceleration between 1.71 and 3.58 *g* as measured by accelerometer MEMS, SMB380 (Micro-electro-mechanical system, Bosch Sensortec Gmbh, Germany) in a separate measurement in 5 young adults lying supine and with the vibration devices on the body in the same way as during training. The accelerations in different combinations of vibration parameters were recorded for a period of 60 seconds each. The frequency, the duration and the number of bouts as well as the duration of the rest periods were adjustable and displayed on the control unit. The vibrators were attached to the body by a strap. The motor control of the vibrators ensured that the set vibration parameters remained constant independently of the applied strap pressure. Because of the structure of the underlying limb, the centrifugal forces on the body were buffed (mass-spring system). The motor control of the vibrators ensured that the set vibration parameters remained constant independently of the applied buffing by the body.

(Figure 2 about here)

Intervention

The participants were instructed how to apply the vibrators in supine lying position once per day, 5 days/weekly for a period of 6 months, at home. All participants applied the vibrators on the mid-thigh (m. quadriceps) and around the hip (m. gluteus maximus and m. gluteus medius) using bandages. The required vibration program was set up before each training period. After the end of the daily set-up training period, the vibration device stopped automatically. Every week one training session was supervised by a researcher to ensure that the training protocol was followed correctly. The compliance rate was recorded by the participant by using a calendar book.

During the 6-month vibration intervention period, training loading increased progressively according to the overload principle by increasing the duration and numbers of bouts and shortening the rest periods as well as increasing the acceleration and the frequency of the training (Table 1).

(Table 1 about here)

The first 11 weeks, vibrators were applied on each side – 1 on the hip and 1 on the mid-thigh, respectively. From 12th week till the end of the 6-month period, 3 vibrators were applied on each side – 1 on the hip and 2 on the thigh, respectively to allow further increase of the training stimulus for the muscle. The vibrators were applied first on the right or left side and then on the other one. The duration of one session lasted for a maximum of 30 minutes.

The participants of the control group were not involved in any additional training program and were asked not to change their lifestyle.

Measurements

To evaluate safety, compliance, and feasibility, all subjects were encouraged to report possible (side) effects or occurrence of falls during each training session. At the end of the study, each participant filled in a questionnaire about the training protocol and the usage of the vibration device.

Bone mineral density, muscular strength and muscle mass, as well physical performance were assessed at baseline and at 6 months in both groups. The assessors for BMD and muscle mass were blind to the patients' allocation to both the experimental and the control group. For practical reasons, it was not possible to have an assessor for muscular strength, SWT and mPPT blinded for group allocation as there was no extra senior evaluator available who was not involved in the training program.

Muscle strength

Muscle strength was recorded unilaterally on the right side on a motor-driven isokinetic dynamometer (Biodex Medical Systems Inc, New York, USA) by means of a standard protocol of dynamic and isometric tests (38). The reliability of isokinetic dynamometry was assessed in our laboratory in older people aged 65 to 79. High ICC's are achieved for the isometric tests (ICC=.89–.99) and for the isokinetic tests (ICC=.95–.97). For the isotonic tests, ICC's gradually decreased as the external resistance increased (ICC's from .89-.83 with external resistance from 0% to 40% respectively).

Isometric strength: the participants performed a maximal voluntary muscle contraction of the knee extensors peak torque (Nm) was recorded. The knee joint angle was set at 30°, 60° and 90°.

Isokinetic strength: the participants performed a series of isokinetic flexion-extension movements against the lever arm of the dynamometer. The velocity was set at 60°/s, 180°/s and 240°/s. The knee extension was initiated at a joint angle of 90° and ended at 160°, and the peak torque was assessed (Nm).

Isotonic strength: the participants performed several ballistic tests with a resistance of 0%, 20% and 40%. The degree of resistance was individually determined as a percentage of the isometric maximum in the knee angle of 90°. The maximal velocity of the lever arm was recorded to determine the ballistic strength. The knee extension was initiated at a joint angle of 90° and ended at 160°. After each extension, the leg was passively returned to the starting position.

Muscle mass

Muscle mass of right upper leg was assessed by multislice computed tomography (CT) scan (Siemens Sensation 16; Forcheim, Germany) and the delivered axial slices of legs were analyzed with the program Volume. The test was previously described by our research group and the reliability was tested, which yielded an intraclass correlation coefficient of 0.99 (2). The summed muscle volume (in cubic centimeters) was analyzed. Measurements were performed in the University Hospital and were executed by an expert radiologist.

Bone mineral density

BMD of the right hip was assessed by DXA using the QDR- 4500A device (Hologic, Waltham, MA, USA). Standard positioning was used with anterior–posterior scanning of the proximal femur. The CV for total hip DXA measurement in our laboratory is 0.56% (37).

Physical performance

To evaluate the functional capacity, a modified physical performance test (mPPT) for elderly was performed. mPPT includes different timed or graded functional tests described previously (26). Additionally to mPPT, physical fitness was assessed using the shuttle walk test (SWT) which is a standardized incremental submaximal field walking (33).

Statistical Analyses

Due to the small sample size, between- and within-group differences in muscle strength, muscle mass and bone mineral density were tested with nonparametric tests. Mann-Whitney U tests were used to compare the baseline characteristics of the vibration and the control groups. A Shapiro–Wilkinson W test was used to assess the distribution for muscle strength, muscle mass and bone mineral density. Additionally, the Cohen's d effect size was calculated based on means and SD. For Cohen's d an effect size below 0.3 is considered as "small" effect, around 0.5 as "medium" effect and 0.8 to infinity as "large" effect. The significance levels for all analyses were set to $P<0.05$. All analyses were executed using the statistical package STATISTICA (STATISTICA Inc, Version 9).

RESULTS

Subjects

The baseline characteristics of the two groups are presented in Table 2. The intervention group’s average weight was 9 kg higher than the control group ($P<0.015$), and the body mass index (BMI) of the intervention group was 3 kg/m^2 higher compared with controls ($P<0.045$).

(Table 2 about here)

Two participants in the intervention group did not complete the full training protocol due to reasons unrelated to the training 1) personal reasons (dropped out after 6 weeks of vibration), and 2) surgical intervention (dropped out after 3 weeks of vibration). Two participants in the control group refused to repeat the tests after the 6 months period due to personal reasons. The average compliance with the vibration intervention was excellent (X: 96.5%). All participants tolerated the vibration protocol well and they did not consider the training as unpleasant. None of subjects reported any adverse effects due to vibration. However, in the questionnaires after the 6-month period, 80% of participants in the vibration group reported that applying the vibrators 5 days/weekly was time consuming and they did not show the willingness to participate in a vibration training program for a longer period.

Effect of the intervention

No significant differences were observed at baseline between the experimental and the control groups in terms of BMD, muscle strength, muscle mass, fat mass, or physical performance (Table 2).

Muscle strength

Significant between-group difference after the 6-month local vibration training was found in favor of the vibration group only in isometric knee extension strength of 60° with a net benefit of 13.84% (P=0.01). No between-group differences were found in the other isometric, isokinetic and isotonic muscle strength tests (P>0.05).

The effect size based on between-group differences is presented in figure 3. The Cohen's *d* effect size for isometric knee extension strength of 60° was large, + 1.02. The effect size of the intervention for the other isometric, isokinetic and isotonic tests appeared small to medium (0.1 – 0.8).

(Figure 3 about here)

Concerning the within-group differences, isometric strength of 60° and 90° of the knee extensors significantly increased by 12.88% (95% CI, 0.8–20.4; P<0.05) and 6.61% (95% CI, -1.16–15.7; P<0.05), respectively, in the vibration group after the 6-month local vibration training (Figure 4).

(Figure 4 about here)

Isokinetic knee flexion strength of 60°/s and 180°/s changed significantly over time in the vibration group by 23.00% (95% CI, 0.00–55.6; P<0.05) and 24.06% (95% CI, 4.91–45.8; P<0.05), respectively. No within-group differences were found in the other isometric, isokinetic and isotonic muscle strength tests in either the vibration or the control group (P>0.05, Figure 4).

Bone mineral density

As shown in Table 3, total hip BMD did not significantly change over time in both vibration and control groups, and additionally, no between-group difference was observed between the two groups (P>0.05).

Muscle mass

Total muscle or fat mass volume did not change significantly over time in either the vibration or the control group and no between-group differences were observed between the two groups (P>0.05, Table 3).

Physical performance

As shown in Table 3, no within-group difference in physical performance – mPPT or SWT over time was observed in either the vibration or the control group (P>0.05). Similarly, no between-group differences were found between the intervention and the control group after the 6-month training period (P>0.05).

DISCUSSION

This was the first study to investigate the feasibility, safety and compliance of a 6-month local vibration applied 5 times a week (30 – 45 Hz, 1.71 – 3.58 *g*) in postmenopausal women. We hypothesized that the specific local vibration program would be a feasible and safe training method to improve musculoskeletal performance in postmenopausal women.

Overall, no adverse effects due to local vibration were reported and the training intensity was well tolerated. Although, the participants reported that 5 days/week training was time consuming, the average compliance with the intervention was excellent (X: 96.5%). Moreover, the participants did not consider the training as difficult, suggesting that local vibration training may be a feasible training program for postmenopausal women.

The main outcomes of the study indicated that the specific vibration program has potential beneficial effects on some aspects of knee muscle strength, but failed to affect bone formation, muscle mass or physical performance in postmenopausal women.

In this study, a local vibration training applied on the hip and mid-thigh resulted in an improvement in some aspects of knee isometric and isokinetic muscle strength. Isometric knee extension strength of 60° and 90° increased significantly by 12.88% and 6.61%, respectively, in the vibration group after the 6-month local vibration training. The standardized Cohen's *d* effect size reflected a small to large mean effect on muscle strength as a result of the vibration intervention, which supports the likelihood of a clinically meaningful effect only on muscle knee strength in a larger randomized controlled trial.

Only very few studies investigated the effect of locally applied vibrations on muscle strength (17,24). In a study by Pietrangelo et al. (24) local vibration training was applied close to the tendon of the quadriceps once to three times a week to a group of male and female elderly (65 – 85 years of age). Twelve weeks of high-frequency local vibration training (frequency of 300

Hz) resulted in a significant improvement between 41.7% and 81.2% in isometric knee extension strength. Vibration frequency used by Pietrangelo et al. was much higher compared to our study (300 Hz to 30 – 45 Hz), however, they did not reported the applied amplitude and acceleration of the vibration and the sample size was very small which might have contributed to the different findings. In a study by Lapole and Pérot (17), 14 days of locally applied vibration (50 Hz, 0.2 mm) directly to the Achiles tendon resulted in a greater triceps surae force production. The authors concluded that the specific local vibration training may be beneficial to persons who are not suitable for WBV training.

In addition, our findings are in line with previously reported WBV studies in elderly (3,27,38). In the study by Verschueren et al. (38) 6-month WBV (35 – 40 Hz, 2.28 – 5.09 *g*) resulted in 15% and 16% a net benefit of isometric and dynamic knee strength in postmenopausal women, respectively. Likewise, in another study with WBV, 12 months of vibration training improved isometric knee strength by 9.4% among older adults (3). Roelants et al. (27) reported a significant increase in isometric (15%) and dynamic (16.1%) knee extensor strength after 6 months of WBV (35 – 40 Hz, 2.28 – 5.09 *g*) in elderly. It has been suggested that vibration training may increase muscle strength by similar mechanisms as during resistance training (4). The first mechanism of adaptation is neural adaptation including an increase in motor unit synchronization, inhibition of the antagonist muscles, or co-contraction of the synergist muscles (8). Strength gain may also increase the ability of motor units to fire briefly at very high rates (22). After several months of training, the changes in the morphological structure of the muscle become dominant (31). However, the present study failed to find any changes in muscle mass after 6 months of local vibration training and therefore, the neural adaptations seem a more relevant mechanism of strength gain. The supine lying static position taken by the participants may contribute to the lack of changes in other aspects of isometric and dynamic muscle strength. In addition, the older age is associated with a decline in the number of muscle spindles which leads to a reduced muscle sensitivity to mechanical loading (34).

In addition, present findings showed a significant improvement in isokinetic knee flexion strength of 60°/s and 180°/s in the vibration group by 23.00% and 24.06%, respectively. This improvement in the flexion knee strength is surprising as the vibration was applied directly to the quadriceps while the participants were in a static supine-lying position. We can only speculate at this time that vibration signal was transmitted to the hamstring muscles in a sufficient way to activate the muscles. The intensity of muscle activation due to vibration reached hereby the threshold for adaptation in the knee flexor muscles but was not high enough in this pilot study to result in significant adaptation in the (stronger) extensor muscles.

The current study failed to show any effect of local vibration training on knee isotonic muscle strength (resistance of 20% and 40% of the isometric maximum). In contrast, one WBV study did report an improvement in knee-extension speed of movement with an external resistance of 1%, 20%, 40%, and 60% of isometric maximum after 6 months of vibration in postmenopausal women (27). It has been suggested that the vibration training results in a more rapid activation and training of high-threshold motor units (28), which contributes to maximal velocity muscle strength. However, the present findings cannot confirm these suggestions. In addition, the isometric maximum – 90° improved significantly in the vibration group after the local vibration training, which resulted in higher tested resistances (20% and 40%) compared to baseline.

The results of the present study failed to show an effect on BMD after 6-months of local vibration training. In contrast to our findings on BMD, a few randomized control trials have shown a significant increase in the BMD of the total hip, femoral neck and/or lumbar spine after WBV training (11,12,30,38). Following 6-month WBV training (35 – 40 Hz, 2.28 – 5.09

g), Verschueren et al. (38) reported a net benefit of 1.5% BMD at the hip in postmenopausal women. Gusi et al. (11) found a net benefit of 4.3% BMD at the femoral neck in postmenopausal women who followed 8 months of vibration intervention (12.6 Hz, 3.3 *g* – lateral, 0.7 *g* – vertical) in comparison with walking group. WBV training with vitamin D supplementation (35 – 40 Hz, 1.6 – 2.2 *g*) improved BMD of the hip compared with baseline in postmenopausal women (37). However, vibration intervention did not result in an additional increase in BMD of the hip compared with controls independently of the additional vitamin D supplementation.

Up to our knowledge, this study was the first to assess the effects of locally applied vibration training on BMD. In the present study, the lack of changes in bone density may be a result of different factors. The vibration loading was considered as reasonable for postmenopausal women and was based on loadings as induced by whole-body vibration training shown before to be effective on bone formation (38). However, the applied frequencies between 30 and 45 Hz and accelerations between 1.71 and 3.58 *g* might not have been optimal to induce higher bone responses. Moreover, while standing on a WBV platform and performing dynamic exercises, the subject experiences both ground reaction and muscle forces which contribute to bone formation (13). However, local vibration training was in a supine lying static position and therefore, the participants were not exposed to weight-bearing loads, which may explain the lack of changes in bone density. Additionally, fat mass around the hip may alter the transmission of the vibration signal from the vibrators to the bone. Moreover, it may be speculated that the induced muscle forces could alter the damping properties of the muscles and thus, alter the transmission of the vibration signal through the body (35). Therefore, the positioning of the vibrators on the hip may not have been optimal enough to reach the target zones sufficiently. A more optimal musculoskeletal response might be achieved if the vibration stimulus is applied in other loading directions. Further studies should quantify the effect of different positions of the local vibration device on musculoskeletal performance.

Study limitations

Our study has limitations and the results should be interpreted in the context of its design. First, our sample size was small, and we acknowledge that this was an exploratory pilot study with no formal sample size calculation. Moreover, due to the intensive vibration training, it was difficult to recruit more participants who could meet the inclusion and exclusion criteria, and who showed a willingness to participate in the trial. Second, we tested only one training regime – training 5 days/weekly, frequency between 30 and 45 Hz, and acceleration between 1.71 and 3.58 *g*. The vibrators were positioned only on the mid-thigh and around the hip which might not have been an optimal training program. Furthermore, the participants took only a supine lying static position and they did not perform simultaneously any dynamic exercises. Third, when the findings of the present study are interpreted, it should be mentioned that significant differences in weight and body mass index were found at baseline between the vibration and the control groups. However, all other baseline tests did not differ between the groups which makes them comparable by means of physical performance, bone mineral density and muscle strength. The manner by which the higher weight influenced the transmission of the vibration signal from the vibrators to the hip cannot be further discussed. Finally, our preliminary findings may only be generalized to a select group of older people and not to younger adults or older men.

PRACTICAL APPLICATIONS

The results of this randomized controlled pilot study indicate the potential of locally applied vibrations to improve different aspects of muscle strength in postmenopausal women. Coaches and practitioners should know that the present training protocol of 6 months locally applied vibration on the hip and mid-thigh seems feasible and safe training method for elderly to improve muscular performance. Local vibration training might be more adequate training approach for a large segment of the frail elderly who are unable to stand on a whole-body vibration platform. Delivering the vibration locally at the regions which are most in need of muscle strengthening might be a more suitable approach.

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Figure legends:

Figure 1. Flow chart of the participants.

Figure 2. Control unit and vibrators.

Figure 3. Effect of the intervention presented as Cohen’s d effect size. The effect size is based on between-group differences of the paretic leg. An effect size below 0.3 is considered as "small" effect, around 0.5 as "medium" effect and 0.8 to infinity as "large" effect. (E – extension, F – flexion)

Figure 4. Mean and SE before (pre) and after (post) 6 months of local vibration training.

NOTE. VIB – vibration group, CON – Control group, ISOM – isometric muscle strength, ISOK – isokinetic muscle strength, ISOT – isotonic muscle strength.

* Within-group difference: a significant difference between baseline and post measures (P<0.05)

Table 1. Characteristics of the vibration training program

Period (week)	Intensity					Vibrators	
	Volume Duration (seconds)	Frequency (Hz)	Acceleration (g)	Rest (seconds)	Bouts	Thigh	Hip
1 → 2	30	30	1.71	60	4	1	1
3 → 6	60	35	2.94	60	5	1	1
7 → 11	60	40	3.40	30	5	1	1
12 → 16	60	40	3.40	30	5	2	1
17 → 21	60	45	3.58	30	7	2	1
22 → 26	60	45	3.58	30	8	2	1

Table 2. Subjects characteristics at baseline and differences between groups.

NOTE. Values are mean ± SD or ranges in the parentheses.

* Between-group difference: a significant difference between vibration and control groups

Parameter	Vibration	Control	P-value
N	17	18	
Age (years)	75.7 (66–84)	77.6 (68–88)	0.39
Height (m)	1.58 (1.5–1.7)	1.57 (1.46–1.65)	0.45
Weight (kg)	73.4 (55– 93)	64.1 (41– 88)	0.015*
BMI (kg/m^2)	29.3 (20.9–36.2)	26.1 (17.1–34.2)	0.045*
Total hip BMD (g/cm^2)	0.834 ± 0.137	0.836 ± 0.114	0.83
Muscle mass (cm^3)	83.7 ± 10.8	79.4 ± 12.3	0.41
Fat mass (cm^3)	110.2 ± 26.6	98.6 ± 30.5	0.41
Isometric strength (Nm)			
• 30°	42.0 ± 11.0	48.8 ± 13.0	0.16
• 60°	91.2 ± 23.9	96.6 ± 20.7	0.24
• 90°	103.7 ± 24.6	105.0 ± 30.7	0.95
Isokinetic strength (Nm)			
• 60°/s–extension	87.3 ± 23.7	84.0 ± 22.4	0.98
• 60°/s–flexion	34.9 ± 12.6	35.0 ± ± 9.2	0.79
• 180°/s– extension	53.2 ± 13.2	50.5 ± 12.5	0.88
• 180°/s– flexion	30.0 ± 9.4	31.1 ± 7.9	0.75
• 240°/s– extension	50.7 ± 11.1	47.9 ± 12.4	0.72
• 240°/s– flexion	33.9 ± 8.3	35.7 ± 11.2	0.69
Isotonic strength			
• 0%	316.8 ± 35.1	319.8 ± 52.2	0.63
• 20%	243.7 ± 42.2	234.2 ± 41.3	0.72
• 40%	138.1 ± 47.0	130.7 ± 22.2	0.35
Physical performance			
• mPPT, points	33.5 (28–36)	32.5 (25–36)	0.35
• SWT, m	317.1 (180–469)	307.8 (188–447)	0.71

Table 3. Mean Changes and Between – Group Differences in Muscle Strength, Shuttle Walk Test (SWT) and Modified Physical Performance Test (mPPT)

NOTE. Values are presented as a percentage of the baseline measures ± SD and 95% CI if not indicated differently.

Parameter	Vibration	Control	Between-group difference	
			Mean	P-value
Total hip BMD	−1.34 (±2.56; −3.55-1.11)	−0.23 (±2.18; −1.68-1.89)	−1.11	0.16
Muscle mass	−0.759 (±3.48; −5.4-1.67)	−1.161 (±4.38; −4.87-2.73)	+0.410	0.87
Fat mass	+0.916 (±4.49; −3.74-6.80)	−1.896 (±8.07; −11.8-4.85)	+2.812	0.17
Physical performance				
• mPPT, points	+0.21 (±2.12; −3-2)	+0.47 (±2.87; ; −1-2)	−0.26	0.65
• SWT, m	−1.21 (±39.4; −39-46)	+4.73 (±55.0; −30-39)	−5.94	1.00

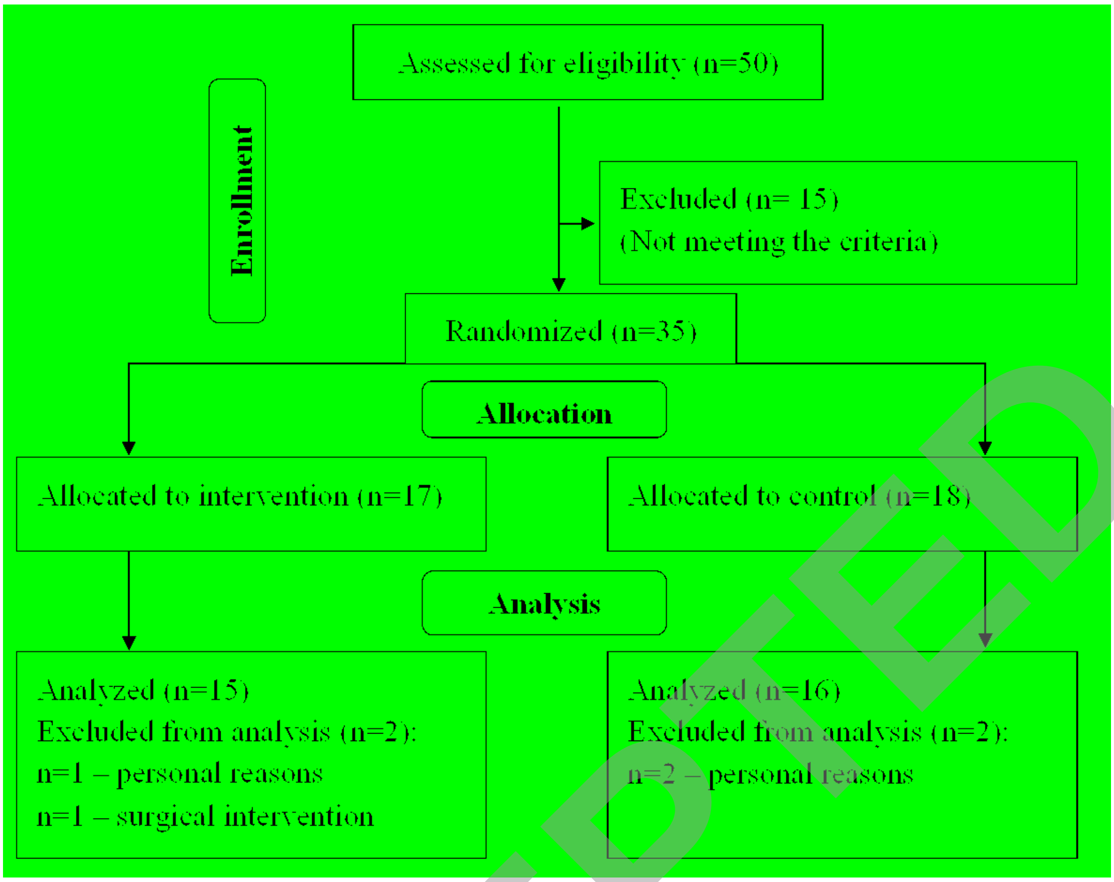

Assessed for eligibility (n=50)
Enrollment
Excluded (n= 15)
(Not meeting the criteria)
Randomized (n=35)
Allocation
Allocated to intervention (n=17)
Allocated to control (n=18)
Analysis
Analyzed (n=15)
Excluded from analysis (n=2):
n=1 – personal reasons
n=1 – surgical intervention
Analyzed (n=16)
Excluded from analysis (n=2):
n=2 – personal reasons

Figure 2. Control unit and vibrators.

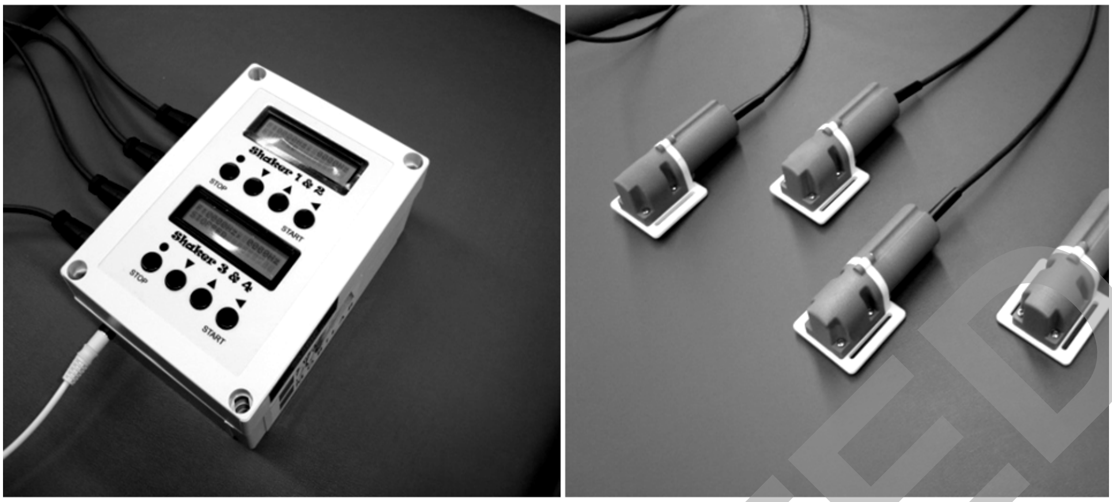


Figure 3

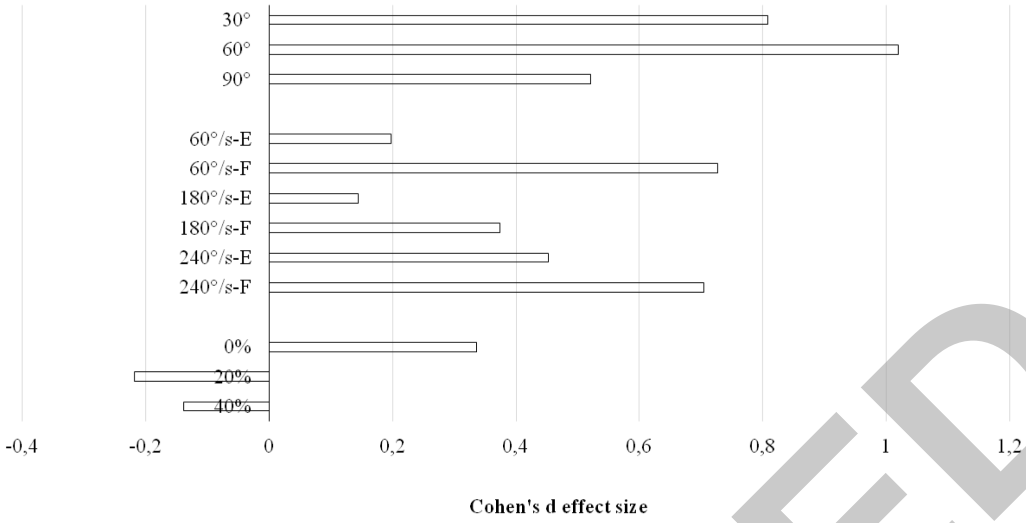
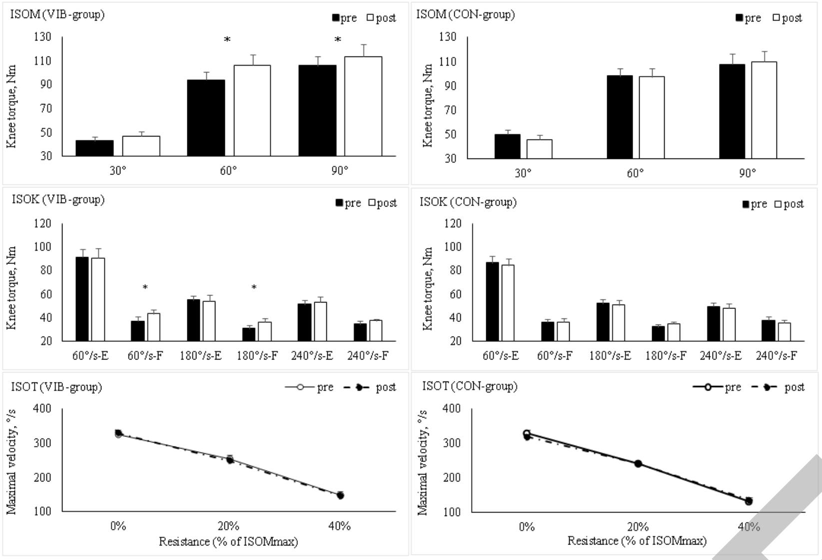

30°
60°
90°
60°/s-E
60°/s-F
180°/s-E
180°/s-F
240°/s-E
240°/s-F
0%
20%
40%
-0,4
-0,2
0
0,2
0,4
0,6
0,8
1
1,2
Cohen's d effect size

Figure 4


ISOM (VIB-group)
■pre □post
Knee torque, Nm
130
110
90
70
50
30
30°
60°
90°
*
*
ISOM (CON-group)
■pre □post
Knee torque, Nm
130
110
90
70
50
30
30°
60°
90°
ISOK (VIB-group)
■pre □post
Knee torque, Nm
120
100
80
60
40
20
60°/s-E
60°/s-F
180°/s-E
180°/s-F
240°/s-E
240°/s-F
*
*
ISOK (CON-group)
■pre □post
Knee torque, Nm
120
100
80
60
40
20
60°/s-E
60°/s-F
180°/s-E
180°/s-F
240°/s-E
240°/s-F
ISOT (VIB-group)
pre
post
Maximal velocity, °/s
400
300
200
100
0%
20%
40%
Resistance (% of ISOMmax)
ISOT (CON-group)
pre
post
Maximal velocity, °/s
400
300
200
100
0%
20%
40%
Resistance (% of ISOMmax)