

Original Article

Effects of whole body vibration training on isokinetic muscular performance, pain, function, and quality of life in female patients with patellofemoral pain: a randomized controlled trial

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Abstract

Objectives: To investigate the effects of whole body vibration (WBV) training on isokinetic muscular performance, pain, function, and quality of life in patients with patellofemoral pain (PFP). **Methods:** Forty women with PFP were included in this study and assigned to either a WBV group that received WBV training plus home exercise or a control group that performed home exercise only. A supervised WBV training was performed in 24 sessions on a synchronous vertical vibration platform three times a week for eight weeks. The home exercise program in the control group was identical to that in the WBV group. Isokinetic measurements were performed at baseline and post-treatment. In addition, patients were assessed after 6 months using a visual analog scale (VAS), Kujala Patellofemoral Score (KPS), and Short Form-36 (SF-36). **Results:** Total work of knee extensors and VAS improved significantly post-treatment in the WBV group compared to the control group ($P=0.041$, $P=0.003$, respectively). However, there was no significant difference between groups at the 6-month follow-up ($P>0.05$). **Conclusions:** The present findings recommended that eight weeks of WBV training plus home exercise can more effectively reduce pain and improve the endurance of the knee extensors than that of home exercise of patient with PFP.

Keywords: Exercise Therapy, Female, Knee, Vibration, Visual Analog Scale

Introduction

Patellofemoral pain (PFP) is the most common knee condition in primary care, orthopaedic, sports medicine, and rehabilitation clinics and is highly prevalent among both athletic and non-athletic adolescents and young adults^{1,2}. The prevalence of PFP is estimated as 25% of the general

or sporting population^{1,3}. Epidemiologic studies have shown a higher incidence of PFP in female patients, ie approximately twice as great⁴. Female athletes active in recreational and competitive sports have a higher risk^{5,6}. The etiology of PFP is multifactorial, with patellar maltracking and joint overload leading to muscle imbalance, lower extremity malalignment, and overactivity². Each of these causative factors plays an important role in the development and persistence in the pathogenesis of PFP. Altered neuromuscular function of the lower extremity could result in an increased the hip adduction and internal rotation, leading to excessive dynamic knee valgus during functional tasks^{7,8}.

The treatment of PFP varies from medication, taping, bracing and up to different rehabilitation approaches, including strength exercises, balance and proprioceptive exercises^{9,10}. Based on the pathogenesis of PFP, exercise can be a causal therapeutic approach with proven superiority

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compared to other approaches¹¹. The literature suggests that exercise therapy for PFP is effective in reducing pain and improving function, as well as maintaining long-term recovery¹²⁻¹⁴. Although exercise therapy as a PFP treatment is widely advocated, there is a lack of evidence to determine the best type of exercise therapy. Strength training focused on strengthening the knee extensor and hip abductor muscles has been shown to be effective for the management of PFP^{10,15}.

Recently, whole body vibration (WBV) training has been suggested due to its strong favorable effects on improving muscle strength and power, balance, function, or reducing pain¹⁶⁻¹⁸. Previous studies have shown that WBV training improves knee pain, knee function and muscular performance in individuals with knee osteoarthritis (KOA)¹⁹⁻²². Therefore, WBV can be an effective and alternative option as a training technique for PFP. A vibratory platform generates vertical sinusoidal vibrations producing reflex muscle contraction, termed a tonic vibration reflex associated with Ia-afferents of the muscle spindles, resulting in facilitating homonymous α -motor neurons during this type of training²³. The enhanced excitability of the muscle spindles may lead to neuromuscular facilitation including increased motor unit recruitment and synchronization of the motor units¹⁶. However, there is some controversy regarding the adding WBV to an exercise regime when compared with exercise only. Some studies indicated to increase in strength, power and jump performance with vibration stimuli when added to resistance training in healthy elderly participants and volleyball players^{24,25}; whereas others demonstrated no significant effects of WBV in healthy young participants and female athletes²⁶⁻²⁸. Optimal treatment protocol including the determination of vibration frequency and peak-to-peak displacement and the amount or duration of treatment should be established for effective WBV training.

While it has been stated that WBV training has beneficial effects as a strength training technique for patients, there is no study demonstrating the effectiveness of WBV training in patients with PFP. This study was designed to test the hypothesis that WBV training is superior to home exercise in female patients with PFP.

Materials and methods

Study design and randomization

This study was a prospective randomized-controlled, clinical trial, which was conducted between February 2015 and February 2016, at the Department of Physical Medicine and Rehabilitation in the Faculty Hospital. The Faculty's Local Ethics Committee in accordance with the Declaration of Helsinki approved the study protocol. All patients provided written informed consent at the beginning of the study after receiving full information about its procedures and purposes. This study was approved by the Research Ethics Committee at Istanbul University (IRB Study protocol: 2014/1552).

Patients were randomly assigned equally to a WBV plus

home exercise (intervention) group or a home exercise only (control) group using a computer-generated programme with an allocation ratio of 1:1 and without varying blocks immediately after clinical examination by one of the investigators (S. Yakal), who informed the non-blinded administering physician (C. Basoglu) about the allocation of the study patients to the WBV or control groups. All assessments and data collection were performed by a single assessor (M. Corum) who was blind to the groups to which the patients had been allocated and conducted procedures in both groups.

Participants

Sixty-six consecutive patients with knee pain who were evaluated for eligibility for the study initially. Among these patients, a total of 40 women aged between 18-40 years diagnosed with either unilateral or bilateral PFP with at least three months symptom history with an average pain during activity (previous week) equal to or greater than 3 cm on a 10 cm visual analogue scale (VAS). Diagnosis of PFP was based on clinical criteria of peri- or retropatellar pain on at least 2 of the following activities such as prolonged sitting, squatting, ascending or descending stairs, kneeling, hopping, or running and positive clinical patellar test²⁹⁻³¹ (Clarke's test or patellar femoral grinding test). Exclusion criteria were as follows: participation in any systematic training programs such as strengthening and/or aerobic exercises, having received any treatment for PFP within the previous three months, history of lower extremity surgery, lower extremity trauma in the past year, and/or fracture, presence of musculoskeletal diseases such as acute herniated disc or spondylolisthesis, any structural disturbances of the lower extremity (e.g. osteoarthritis in hip or knee joints, prosthesis), central or peripheral neurological pathology and any chronic disease (e.g. diabetes mellitus), presence of gall or kidney stones and intraocular lenses, smoking and excessive alcohol intake, malignancy, and pregnancy. All patients of both groups were required to participate in at least 19 out of the 24 treatment sessions (80%) for the final analysis. In the control group, patients recorded their exercises over the 8-week period.

Vibration training

WBV training was performed on a tri-planar (mostly vertical, Z axis) oscillating vibration platform (Power Plate[®] pro5[™]; Power Plate North America, Inc., Northbrook, IL, USA) for 20-30 minutes per session. WBV training was supervised and performed in a clinic three days a week with at least one day between each session for eight weeks (total of 24 sessions). Each session lasted approximately 40 minutes including a 10 minutes warm-up and flexibility training period (5 minutes lower extremity stretching exercises and 5 minutes cycling [50 watts] on a stationary bike), a 20-30 minutes period of WBV training and 5 minutes cool-down period (lower extremity stretching exercises). Lower extremity stretching exercises consisted of quadriceps,

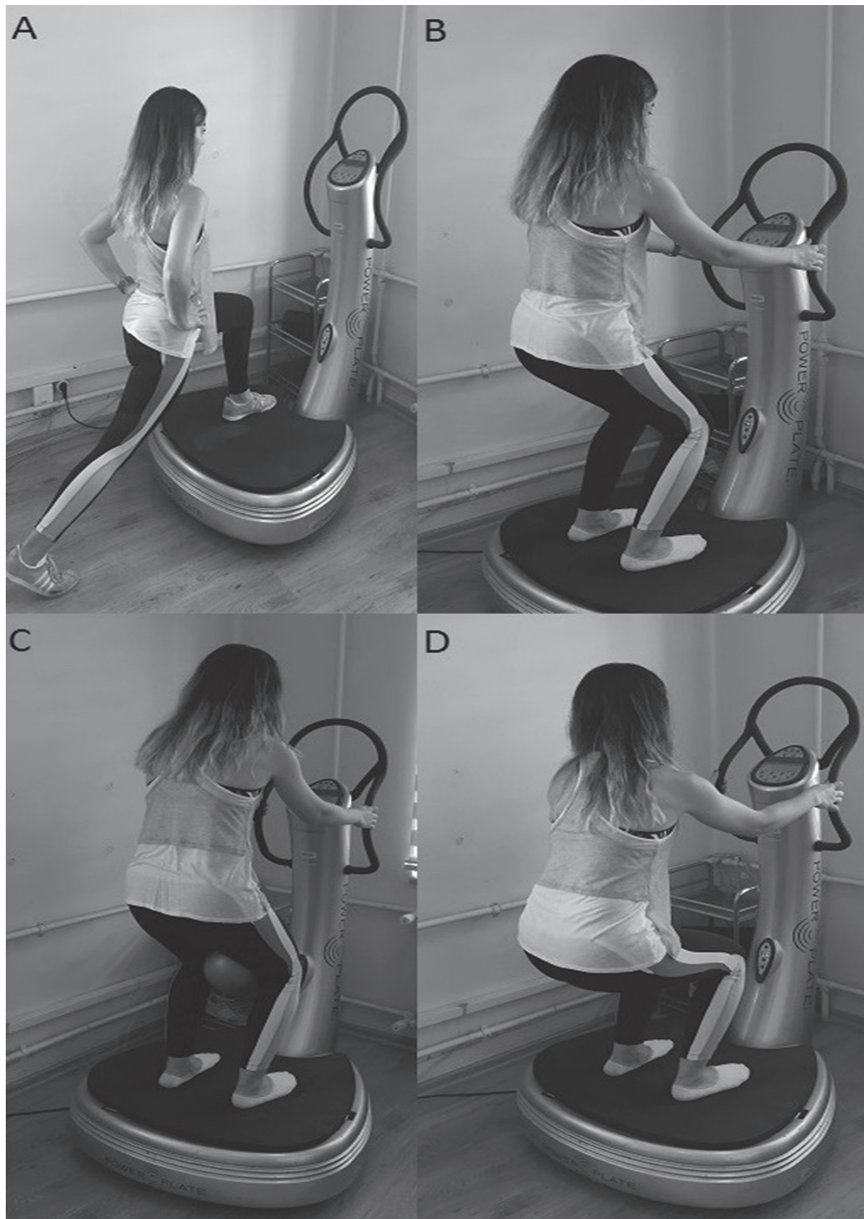


Figure 1. WBV training position of each exercise. (A) Lunge-step, (B) semi-squat, (C) ball- squeeze squat, and (D) dynamic squat.

hamstring, gastrocnemius and iliotibial band stretching.

The frequency of the vibration platform (amount of vibrations per second) was fixed at 35 Hz during the eight weeks and the amplitude of the vibration platform (peak-to-peak displacement) was set at 2 mm in the first four weeks, and 4 mm during the second four weeks of the study. A total of 4 different types of WBV exercises in 3 sets were applied for 30 or 45 or 60 s/set with a 30 s rest period between sets and a 60 s rest period between exercises. The exposure time to vibration was increased gradually.

The patients of the WBV group were asked to take off their shoes, to stand on the vibration platform with their socks

on, and the correct position on the vibration platform was adjusted before each exercise. The WBV training program used only body weight resistance with no added external weight in the following 3 static exercises and 1 dynamic exercise targeting knee extensor muscles performed by each patient³²⁻³⁵ (Figure 1).

Lunge-step position: The affected side of the foot was placed on the vibration platform with the knee angled at 90° in line with the second digit of the foot in the sagittal plane. Patients were asked to stabilize their hips in a vertical position and the knee was not to be positioned anterior to the toes. The non-affected side of the foot was placed on the ground

and patients could hold onto the handlebars to support their balance. This exercise was performed bilaterally.

Semi-squat position: The patients stood on a vibration platform with feet 20 cm apart while the knees were bent 45 degrees in line with the second digit of the foot in the sagittal plane and were not to be positioned anterior to the toes, and the hips were bent 45 degrees. The patients were asked to keep their backs neutral and they could hold onto the handlebars to support their balance.

Ball squeeze squat position: Similar instructions were given for knee and hip positions as in the semi-squat position, while squeezing the inner thighs to keep the ball steady.

Dynamic squat position: The patients stood on a vibration platform as in the semi-squat position, then both knees and hips were bent from 45 degrees to 60 degrees and extended from 60 degrees to 45 degrees.

Reporting of the study was made according to the recommendations of the International Society of Musculoskeletal and Neuronal Interactions³⁶.

Home exercise

This present study provides equivalent training settings for WBV and control groups regarding the load, volume and type of training. The patients in the control group were instructed on how to perform the exercises at home and supervised individually once a week throughout the program. Each session was performed bilaterally and lasted approximately 40 minutes including 10 minutes warm-up (lower extremity stretching exercises), 20-30 minutes period of strength exercises with three sets of 10-15 repetitions (isometric quadriceps setting, knee extensions, double-legged wall squat), and 5 minutes cool-down (lower extremity stretching exercises). Lower extremity stretching exercises consisted of quadriceps, hamstring, gastrocnemius and iliotibial band stretching with 3 repetitions for 30 s each muscle.

Outcomes

Assessments of the outcome measures were performed at baseline, after 8 weeks of training (post-treatment, at least 72 hours after the last training), and after 6 months (follow-up). Pain, knee function and health-related quality of life were assessed by standardized, validated questionnaires at each time point. The patients were also tested with isokinetic dynamometer at baseline and post-treatment. For patients with bilateral PFP, the most painful knee established on initial assessment was evaluated for all testing sessions.

Primary outcomes: knee extension peak torque at 60°/s and total work at 240°/s

Isokinetic measurements of the quadriceps and hamstring muscle groups were performed bilaterally using a Cybex II isokinetic dynamometer (HUMAC®/Norm™; Computer Sports Medicine, Inc., Stoughton, MA, USA) in both groups. The same test protocol was applied to the patients by a physiotherapist (T. Sahinkaya) experienced in isokinetic assessment who was

blinded to the group allocation and encouraged the patients to give maximum effort with verbal instructions.

Prior to testing, the patients performed 10 minutes warm-up exercises using a horizontal cycle (50 watts). For all isokinetic tests, the patients were placed in an upright sitting position and strapped their chest, waist, and lower limb to stabilize the body. Additionally, each patient crossed their arms over their chest to prevent external forces from the upper body. The angular velocities of 60°/s (four consecutive repetitions) and 240°/s (twenty consecutive repetitions) were determined to provide adequate and reliable data for proper muscular performance. Isokinetic tests were applied for each lower limb, starting from the non-affected knee or less painful knee. For familiarization, three practice repetitions of each angular velocities used in the test were performed before testing. The patients performed a series of consecutive isokinetic knee flexion/extension movements at both velocities against the lever arm of the dynamometer. Peak torque (PT), total work (TW) and the hamstring-to-quadriceps (H/Q) ratio were evaluated, and each parameter was normalized by the body weight of each patient. No resistance or aerobic training was required for at least 72 hours prior to testing to prevent any effects of the last training session on the test results.

Secondary outcomes: pain, self-reported knee function and quality of life

Self-assessment of average pain intensity during activity in the previous week was measured using a 10-cm VAS, in which 0 corresponded to "no pain" and 10 corresponded to "worst pain imaginable". The 10-cm VAS is a reliable and valid outcome measure for the assessment of pain in patients with PFP^{37,38}.

A validated Turkish version of the 13-item Kujala Patellofemoral Score (KPS), which is designed as a knee-specific self-reported questionnaire was used to determine each patient's perceived knee function caused by PFP^{39,40}. Each item is based on six points with the higher scores representing better functional capacity.

Self-reported health-related quality of life was assessed with the Medical Outcomes Study (MOS) with the 36-Item Short Form Health Survey (SF-36), developed for use in a wide range of diseases including PFP^{41,42}. The validity and reliability of the Turkish version of the SF-36 has been demonstrated⁴³. 36 items rated on Likert scales are summed and then transformed to the eight SF-36 subscales and two summary scales: physical component summary (PCS) and mental component summary (MCS) scores. The PCS and MCS scores were preferred to be used for this study. Higher scores represented better health condition.

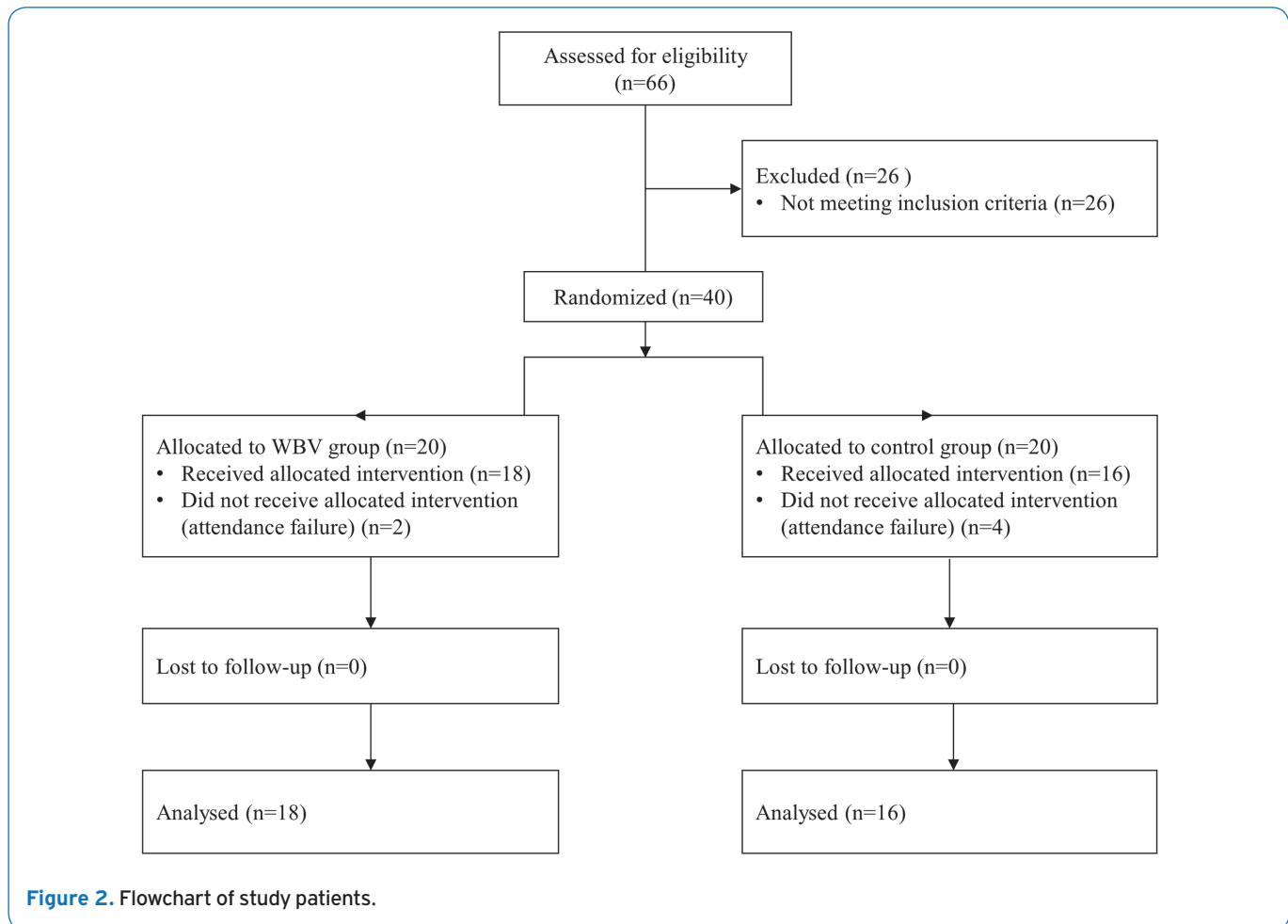
Statistical analysis

The Statistical Package for Social Sciences (SPSS 17.0, SPSS Inc., Chicago, IL USA) software was used for statistical analysis. Descriptive statistics were generated

Table 1. Demographic and clinical characteristics of patients.

	WBV group (n = 18)	Control group (n = 16)	P*
	Mean ± SD or n (%)		
Age (years)	32.7±7.3	33.7±7.7	0.694
Weight, kg	63.1±11	63.0±9,8	0.977
Height, cm	161.0±5.7	163.0±6.3	0.302
BMI (kg/m ²)	24.2±4.2	23.5±3.1	0.564
Affected extremity, right/left	8 (44.4) / 10 (55.6)	10 (55.6) / 6 (37.5)	0.292
Duration of symptoms			
3-month - 6-month	2 (11.1)	4 (25.0)	0.391
6-month - 1-year	1 (5.6)	0 (0.0)	
>1 year	15 (83.3)	12 (75.0)	

Means (SD) is given for continuous variables; n (%) is given for categorical data. SD, Standard Deviation; BMI, body mass index.



for the demographic and clinical variables of patients. Group differences of descriptive data were assessed using the independent-samples t test for continuous variables, and Pearson chi-squared test or Fisher exact test for dichotomous variables. The outcome results are expressed

as mean and standard deviation (SD), with 95% confidence intervals (95% CI). The Shapiro-Wilk test was employed to evaluate data for the normality of distribution. Since all measures were normally distributed, parametric tests were used for all statistical analyses. The paired-samples

Table 2. Analysis of isokinetic performance at measurement intervals in the WBV and control groups.

Outcome measures	Mean \pm standard deviation			Within-group comparisons	Between-group comparisons
	Groups	Baseline	Post-treatment	Mean difference (95% CI); P-value	Mean difference (95% CI); P-value; Cohen's d
PT (Nm/kg), extension, 60°/s	WBV	132.3 \pm 36.5	160.2 \pm 28.7	27.8 (16.0 to 32.9); <0.001*	4.1 (-10.5 to 18.8); 0.571; 0.19
	Control	153.1 \pm 31.0	176.8 \pm 25.9	23.7 (14.5 to 39.7); <0.001*	
PT (Nm/kg), extension, 240°/s	WBV	60.3 \pm 14.7	75.2 \pm 14.0	14.8 (7.9 to 21.7); <0.001*	147 (-2.5 to 16.5); 0.147; 0.51
	Control	71.3 \pm 14.5	79.1 \pm 17.1	7.8 (0.7 to 14.9); 0.032*	
PT (Nm/kg), flexion, 60°/s	WBV	85.6 \pm 21.1	106.6 \pm 15.8	21.0 (12.5 to 29.5); <0.001*	-3.2 (-14.2 to 7.7); 0.551; 0.21
	Control	96.7 \pm 16.6	121.0 \pm 15.2	24.3 (16.7 to 31.8); <0.001*	
PT (Nm/kg), flexion, 240°/s	WBV	49.7 \pm 16.8	64.2 \pm 11.9	14.4 (8.6 to 20.2); <0.001*	5.0 (-2.9 to 13.0); 0.205; 0.44
	Control	55.8 \pm 15.0	65.2 \pm 16.6	9.3 (3.4 to 15.3); 0.004*	
TW (J/kg), extension, 240°/s	WBV	818.7 \pm 246.2	965.2 \pm 225.8	146.4 (44.5 to 248.3); 0.008*	141.9 (6.3 to 277.5); 0.041**; 0.73
	Control	965.3 \pm 244.1	969.8 \pm 226.4	4.5 (-91.6 to 100.6); 0.922	
TW (J/kg), flexion, 240°/s	WBV	771.5 \pm 288.9	954.6 \pm 246.0	183.0 (121.2 to 244.8); <0.001*	86.9 (-12.4 to 186.3); 0.084; 0.60
	Control	829.7 \pm 342.0	925.8 \pm 358.1	96.1 (10.9 to 181.2); 0.029*	
H/Q ratio (%), 60°/s	WBV	66.0 \pm 16.2	67.0 \pm 8.2	0.9 (-6.2 to 8.1); 0.785	3.6 (-11.7 to 4.4); 0.369; 0.31
	Control	64.3 \pm 8.6	68.9 \pm 8.5	4.5 (0.8 to 8.2); 0.019*	
H/Q ratio (%), 240°/s	WBV	82.3 \pm 19.0	85.7 \pm 15.0	3.3 (-4.6 to 11.4); 0.387	2.9 (-12.9 to 7.0); 0.555; 0.21
	Control	76.0 \pm 12.1	82.3 \pm 12.1	6.3 (0.0 to 12.5); 0.048*	

PT, peak torque; TW, total work; H/Q ratio, hamstring-to-quadriceps ratio; CI, confidence interval. * Paired-samples t test. ** ANOVA.

t test was performed to examine the differences occurring at measurement intervals within each group for isokinetic performance assessments (PT, TW and H/Q ratio). The repeated-measures analysis of variance (ANOVA) was used to test the effect of the task on the all outcome measures in the two groups. Post hoc analysis with Bonferroni corrections was performed for multiple comparisons between variables. To estimate effect size, the Cohen's d value was calculated for all outcome measures. Effect size standards were 0.2=small, 0.5=moderate and 0.8=large. A P-value of <0.05 was considered as the significance level.

Results

Participant characteristics

Baseline characteristics of demographic and clinical variables of the patients were summarized in Table 1. The final study sample consisted of 34 patients (n=18 in the WBV and n=16 in the control groups). 6 patients were excluded from the final analysis due to attendance failure (see Figure 2). An intention-to-treat analysis was not performed because the dropout patients were not included in the statistical analysis. There was no statistically significant difference between the groups in relation to demographic and clinical characteristics of the

patients at the beginning of the study. Moreover, there was no significant difference between the two groups at the baseline assessment in terms of all outcome measures.

Primary and secondary outcomes

The PT of knee extensors and flexors exhibited significant differences in both groups at each angular velocities (P<0.05) (Table 2). The TW of knee extensors (t=3.03; 146.4, 95% CI 44.5 to 248.3; P=0.008) and flexors (t=6.25; 183.0, 95% CI 121.2 to 244.8; P<0.001) increased significantly in the WBV group, whereas, the H/Q ratio at 60°/s (t=2.62; 4.5, 95% CI 0.8 to 8.2; P=0.019) and 240°/s (t=2.15; 6.3, 95% CI 0.0 to 12.5; P=0.048) increased significantly in the control group. In the between-group comparison, there was no significant difference between the groups in relation to all items of the isokinetic performance assessments except for the TW of knee extensors (F=4.54; 141.9, 95% CI 6.3 to 277.5; P=0.041). The Cohen's d effect size was 0.73 for TW of knee extensors (Table 2).

The VAS for pain differed significantly between time points in both WBV (F=24.49; P<0.001) and control groups (F=4.00; P=0.046). According to the post hoc analysis, VAS for pain improved within groups significantly in both post-treatment (-3.3, 95% CI -4.4 to -2.3; P<0.001) and at the 6-month

follow-up (-2.2, 95% CI -3.6 to -0.9; $P=0.001$). The patients in the WBV group showed improvements above the minimal clinically important difference (MCID) of 2 points for VAS³⁸ post-treatment (-3.3) and at the 6-month follow-up (-2.2). For the control group there was a statistically significant within group improvement post-treatment which was not clinically significant (-1.5, 95% CI -2.6 to -0.4 $P=0.006$). The between-group comparison of the VAS revealed a significant difference post-treatment ($F=10.02$; -1.8, 95% CI -3.0 to -0.6; $P=0.003$). However, no significant difference was found between the groups at the 6-month follow-up ($F=2.45$; -1.3, 95% CI -3.0 to 0.4; $P=0.127$) (Table 3, Figure 3). The Cohen's d effect sizes were 1.08 post-treatment and 0.53 at the 6-month follow-up for VAS (Table 3).

There was no significant time effect of KPS scores were observed for both WBV ($F=3.15$; $P=0.065$) and control groups ($F=0.35$; $P=0.658$). The KPS scores increased in both groups during the intervention period; however, these increases were not significant. Additionally, the MCID of 10 points for KPS scores⁴⁰ was not observed each time point in both groups. In the between-group comparison, there was no significant difference between the groups in relation to KPS scores post-treatment ($F=0.40$; 2.6, 95% CI -5.9 to 11.2; $P=0.533$) and at the 6-month follow-up ($F=0.44$; 2.9, 95% CI -5.9 to 11.8; $P=0.508$) (Table 3, Figure 3). The Cohen's d effect sizes were 0.21 post-treatment and 0.22 at the 6-month follow-up for VAS (Table 3).

The PCS scores increased significantly between time intervals in both WBV ($F=16.35$; $P<0.001$) and control groups ($F=11.84$; $P<0.001$). The post hoc analysis of PCS scores showed improvements in both WBV (17.9, 95% CI 9.2 to 26.7; $P<0.001$) and control (14.2, 95% CI 7.9 to 20.5; $P<0.001$) groups post-treatment and at the 6-month follow-up (11.8, 95% CI 3.4 to 20.3; $P=0.005$, 10.3, 95% CI 2.3 to 18.3; $P=0.010$, respectively). Significant time effects of MCS scores were found only in the WBV group ($F=5.28$; $P=0.014$). According to the post hoc analysis of MCS scores, the only significant difference was observed in the WBV group at the 6-month follow-up (8.8, 95% CI 1.9 to 15.7; $P=0.010$). When the groups were compared, there was no significant difference between the groups in PCS and MCS scores ($P>0.05$) (Table 3, Figure 3). The Cohen's d effect sizes were 0.30 post-treatment and 0.12 at the 6-month follow-up for PCS scores and 0.22 post-treatment and 0.36 at the 6-month follow-up for MCS scores (Table 3).

Discussion

Our aim in the present study was to use WBV training plus home exercise and compare it against home exercise in patients with PFP. Based on the results of this study, we concluded that WBV training was more effective in reducing knee pain intensity and increasing knee extensor muscular performance in terms of TW. Our findings also indicate that WBV training plus home exercise was not found to be more effective than home exercise alone for efficient functional

enhancement and quality of life improvement.

The results of studies on the effects of WBV training over conventional training on muscular performance are inconsistent in the literature. Delecluse et al⁴⁴ indicated that isometric and dynamic knee extensor strength significantly increased after 12 weeks of WBV training in previously untrained females compared to a placebo group performing static and dynamic knee-extensor exercises (squat and lunge) on a vibration platform with no vibrations. Similarly, a recent meta-analysis⁴⁵ assessing the efficacy of WBV training on muscle strength and power enhancement provided evidence that WBV training can lead to more significant additional effects on knee extensor muscle strength and jumping performance than controls in young and older participants. Contrarily, in the systematic review and meta-analysis study conducted by Rogan et al⁴⁶ investigating the effects of WBV training on muscle strength in healthy elderly participants, WBV training was neither significantly better nor superior than the control group doing conventional exercise. Another systematic review and meta-analysis¹⁹ focused on improved quadriceps function after WBV training in individuals with KOA showed that no difference was found on muscle strength compared to a control group performing the same exercise as the WBV group. In our study, although no difference was observed on muscle strength between groups, we found an additional enhancement on muscular endurance of the knee extensors in the WBV group compared to the control group ($P=0.041$) with a moderate effect (Cohen's $d=0.73$) (Table 2). Our finding demonstrating better effectiveness of WBV training on muscular endurance is important as some studies have reported that WBV training increases muscle fatigue⁴⁷. Maffiuletti et al⁴⁸ showed acute neuromuscular fatigue outcomes after static half-squat exercises in both WBV or non-WBV training. Similarly, a recent study³⁴ demonstrated a decrease in quadriceps strength after static squats on a vibration platform in untrained young males and females. On the contrary, the aforementioned study³⁴ has also shown that the addition of WBV to an acute dynamic squat potentiates an increase in strength. Meta-analyses by Marin and Rhea^{17,18} suggested that dynamic exercises should be used to elicit the greatest benefits on muscular performance with frequencies of 35 to 40 Hz. In this context, it can be said that dynamic exercises and WBV protocols with 35 Hz of vibration frequency added a further effect to WBV training on knee extensor work output in our study. Furthermore, another possible explanation is that the increased muscular endurance in our study may be related to patients experiencing less pain during isokinetic testing of total work at a high angular velocity (240°/s). Higher angular velocities during isokinetic testing have been shown to cause significantly less forcing movements on the knee joint, leading to decrease perceived pain⁴⁹.

In addition, the H/Q ratio significantly increased in the control group in our study. This might be due to the fact that static and dynamic squats and lunge positions produce a greater response to vibration in knee extensor muscles^{50,51}.

Table 3. Within- and between-group comparisons of the pain, function and quality of life variables.

Outcome measures	Groups	Mean ± standard deviation			Within-group comparisons	Between-group comparisons
		Baseline	Post-treatment	6-month follow-up	Mean difference (95% CI); P-value a) Base vs. post b) Base vs. 6-mo	Mean difference (95% CI); P-value; Cohen's d a) Base vs. post b) Base vs. 6-mo
VAS (cm)	WBV	4.9±1.5	1.5±1.6	2.6±2.5	a) -3.3 (-4.4 to -2.3); <0.001† b) -2.2 (-3.6 to -0.9); 0.001†	a) -1.8 (-3.0 to -0.6); 0.003†; 1.08 b) -1.3 (-3.0 to 0.4); 0.127; 0.53
	Control	5.0±1.7	3.4±1.9	4.0±2.2	a) -1.5 (-2.6 to -0.4); 0.006† b) -0.9 (-2.8 to 0.9); 0.619	
KPS	WBV	81.9±6.2	87.5±9.2	85.5±11.5	a) 5.5 (-0.5 to 11.6); 0.080 b) 3.6 (-1.0 to 8.2); 0.167	a) 2.6 (-5.9 to 11.2); 0.530; 0.21 b) 2.9 (-5.9 to 11.8); 0.508; 0.22
	Control	70.4±15.7	73.3±10.8	71.1±14.9	a) 2.8 (-7.0 to 12.7); 1.000 b) 0.6 (-10.6 to 11.9); 1.000	
SF-36, PCS	WBV	50.8±19.1	68.7±20.1	62.7±20.6	a) 17.9 (9.2 to 26.7); <0.001† b) 11.8 (3.4 to 20.3); 0.005†	a) 3.7 (-4.6 to 12.1); 0.374; 0.30 b) 1.5 (-7.3 to 10.4); 0.727; 0.12
	Control	41.2±13.2	55.4±15.4	51.5±15.3	a) 14.2 (7.9 to 20.5); <0.001† b) 10.3 (2.3 to 18.3); 0.010†	
SF-36, MCS	WBV	52.8±16.7	58.7±17.1	61.6±16.3	a) 5.9 (2.6 to 14.5); 0.252 b) 8.8 (1.9 to 15.7); 0.010†	a) 2.6 (-5.6 to 11.0); 0.520; 0.22 b) 4.6 (-4.3 to 10.8); 0.301; 0.36
	Control	47.8±16.0	51.1±17.6	52.0±17.1	a) 3.2 (3.0 to 9.6); 0.545 b) 4.2 (-5.5 to 14.0); 0.791	

VAS, visual analog scale; KPS, Kujala Patellofemoral Score; SF-36, Short Form-36; PCS, physical component summary; MCS, mental component summary; CI, confidence interval. † ANOVA.

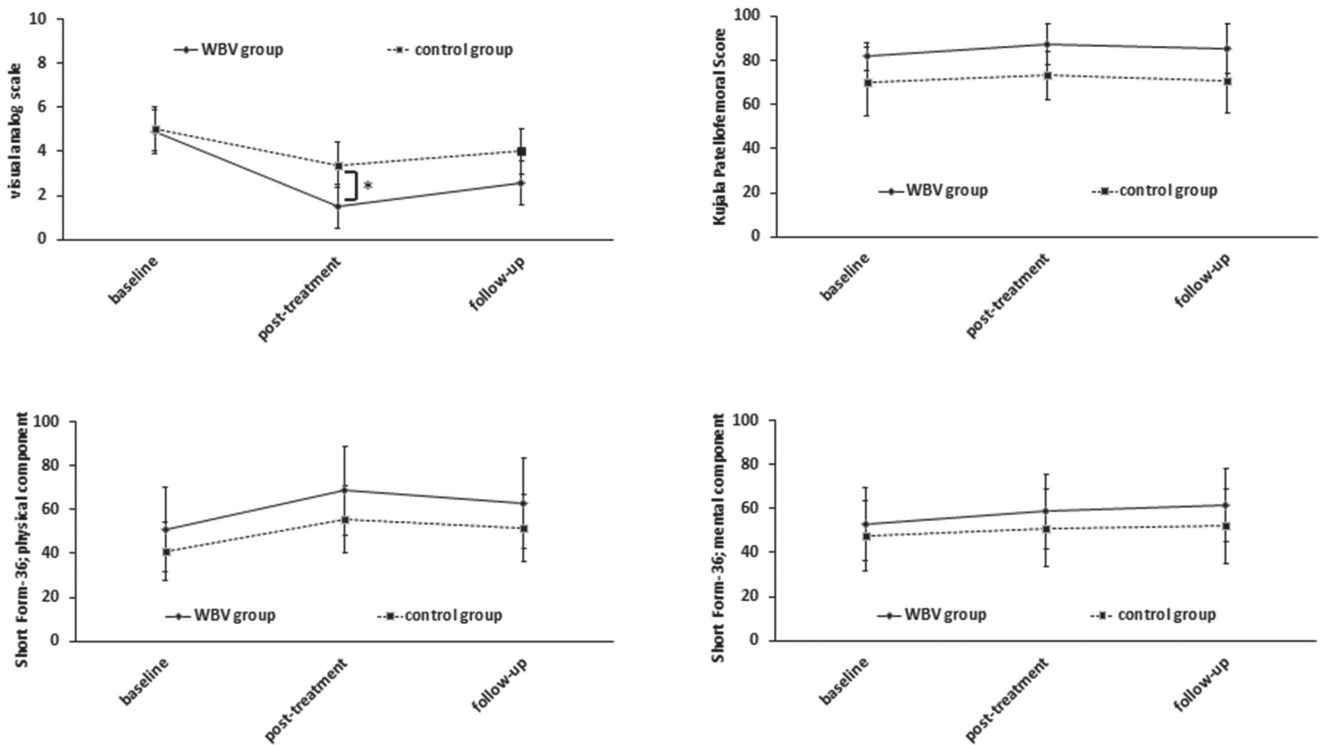


Figure 3. Changes in mean values with standard deviations for visual analog scale, Kujala Patellofemoral Score, Short Form-36 physical component, and Short Form-36 mental component over time in each group. * P<0.05.

Similarly, Bokaeian et al⁵² demonstrated that the addition of WBV training to strength training significantly improved the strength of knee extensor muscles, but not knee flexor muscles compared to strength training alone. In contrast, Karatrantou et al⁵³ showed the positive effect of WBV training on the strength profile of the knee flexor muscles with no improvement to knee extensor muscles. The findings of the study by Karatrantou et al⁵³ contradict with the findings of the present study, which may be due to the use of static semi-squat exercise alone with the knees at a 10° flexion. Furthermore, Yu et al⁵⁴ and Kim et al⁵⁵ indicated that highest muscular activity was found to be in the low squat position. It can be speculated that the WBV training protocol in our study was appropriate for producing efficiently greater activation intensities in the knee extensor muscles.

Regarding knee pain in our study, 2-point MCID difference for VAS was revealed only in the WBV group after treatment (-3.3) and 6 months (-2.2). Significant VAS difference between groups was found only post-treatment with an effect size of 1.08 which could be considered large effect (Table 3, Figure 3). In the systematic review and meta-analysis by Zafar et al²⁰ evaluating the therapeutic effects of WBV training in KOA, there was sufficient evidence to suggest results in favor of additive effects of WBV training for reducing pain and improving function. In contrast, in two systematic reviews and meta-analyses, Wang et al²¹ and Li et al²² reported that the WBV training program could not reduce pain in individuals with KOA despite functional efficacy. Results about the effects of WBV training on reducing pain in certain populations, such as KOA, are inconsistent. On the basis of our data, it can be hypothesized that a reduction in pain may be explained by increased muscular endurance of the knee extensor muscles. The greater knee extensor endurance resulting from the WBV training may play an important role in lower extremity kinematics. A study by Lee et al⁵⁶ reported that greater knee extensor endurance has been shown to correlate with greater knee adduction moments, thus reducing patellofemoral stress. Surprisingly, self-reported knee function did not improve despite our findings of improvements in pain and muscular endurance. It is possible that the relatively short duration of treatment (8 weeks) with WBV training may not alter the physiological mechanisms affecting patients' self-perception of functional outcomes. Also, it is apparent that inadequate self-perception may not accurately reflect the functional outcomes. However, in the aforementioned study by Li et al²² demonstrating an improvement in functional performance in the WBV group, there was no significant change in self-report functions.

Previous studies identified positive results of WBV training on the health status in elderly⁵⁷⁻⁵⁹. This could reflect the improvement in their muscular and balance performance. However, in a systematic review and meta-analysis⁶⁰, WBV training was found not to be effective in the improvement of quality of life in women with fibromyalgia. Only one study by Wang et al⁶¹ evaluated the effects of WBV training on

quality of life in patients with knee pain, in which WBV group presented better performance in their daily activities over a 24-week period. Contrarily, we did not observe significant changes using the SF-36 questionnaire between groups (Table 3, Figure 3).

Strengths and limitations of the study

The major strength of the present study is the fact that it is the only study that compares the effectiveness of WBV training and home exercise in patients with PFP. Also, our study allowed us to evaluate the long-term follow-up effects of WBV on outcome measures. Another strength of the study is that all WBV training sessions were supervised by the one investigator which minimizes variability in the training sessions.

Our study had several limitations that must also be considered. First, the sample size of this study was relatively small so there is a likelihood of a type 2 error indicating that a statistically significant difference may have been present but was missed. Second, since our long-term follow-up did not include isokinetic measurements, we could not observe the long-term effects of interventions on muscular performance. Third, although all WBV training sessions were supervised by the investigator, home-based training was supervised only once a week. Finally, patients were not blinded to treatment due to the study design. But, a blinded external observer was used to provide objective and observational measures of functional outcomes.

In conclusion, this study was able to show the superiority of eight weeks of WBV training plus home exercise over home exercises alone in patients with PFP. Our findings provide potential benefits of vibration stimulus on muscular endurance improvement and pain reduction for PFP. Based on the results of our study, it can be said that WBV training is a feasible and efficient exercise intervention for the management of patients with PFP. However, patients should be assessed with etiologic factors causing their knee pain for the most appropriate treatment of PFP due to its multifactorial nature. We believe that our study contributes to evidence in WBV research by providing an efficient protocol. However, other combinations of exercises on the platform and vibration parameters (duration, frequency, and amplitude) for an optimal effect should be considered in future studies. Further large-scale interventional studies with additional measurement of objective functional tests and a larger number of patients are recommended.

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Author contributions

M. Corum and C. Basoglu conceived the idea and designed the project; M. Corum, C. Basoglu and C. Aksoy were responsible for acquisition, analysis, or interpretation of data; M. Corum and C. Basoglu

analyzed the data; M. Corum and C. Basoglu had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis; M. Corum, C. Basoglu and C. Aksoy drafted the manuscript; S. Yakal performed clinical examination for PFP and allocated the study patient to groups. C. Basoglu instructed and supervised study patients; M. Corum performed all assessments of study; isokinetic test protocol was provided by T. Sahinkaya; all authors interpreted the results and critically revised the manuscript for important intellectual content; all authors approved the final version of the manuscript for publication.

References

- Callaghan MJ, J Selfe. Has the incidence or prevalence of patellofemoral pain in the general population in the United Kingdom been properly evaluated? *Phys Ther Sport* 2007;8(1):37-43.
- Rothermich MA, NR Glaviano, J Li, JM Hart. Patellofemoral pain: epidemiology, pathophysiology, and treatment options. *Clin Sports Med* 2015;34(2):313-27.
- Rixe JA, JE Glick, J Brady, RP Olympia. A review of the management of patellofemoral pain syndrome. *Phys Sportsmed* 2013;41(3):19-28.
- Boling M, D Padua, S Marshall, K Guskiewicz, S Pyne, A Beutler. Gender differences in the incidence and prevalence of patellofemoral pain syndrome. *Scand J Med Sci Sports* 2010;20(5):725-30.
- Dugan SA. Sports-related knee injuries in female athletes: what gives? *Am J Phys Med* 2005;84(2):122-30.
- Nejati P, B Forogh, R Moineddin, HR Baradaran, M Nejati. Patellofemoral pain syndrome in Iranian female athletes. *Acta Med Iran* 2011;49(3):169.
- Powers CM. The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. *J Orthop Sports Phys Ther* 2003;33(11):639-46.
- Nakagawa TH, ÉT Moriya, CD Maciel, FV Serrão. Trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during a single-leg squat in males and females with and without patellofemoral pain syndrome. *J Orthop Sports Phys Ther* 2012;42(6):491-501.
- Werner S. Anterior knee pain: an update of physical therapy. *Knee Surg Sports Traumatol Arthrosc* 2014; 22(10):2286-94.
- Collins NJ, LM Bisset, KM Crossley, B Vicenzino. Efficacy of nonsurgical interventions for anterior knee pain. *Sports Med* 2012;42(1):31-49.
- Van der Heijden RA, NE Lankhorst, R Van Linschoten, S Bierma-Zeinstra, M Van Middelkoop. Exercise for treating patellofemoral pain syndrome. An abridged version of Cochrane systematic review. *Eur J Phys Rehabil Med* 2015;52(1):110-33.
- Kooiker L, IG Van De Port, A Weir, MH Moen. Effects of Physical Therapist-Guided Quadriceps-Strengthening Exercises for the Treatment of Patellofemoral Pain Syndrome: A Systematic Review. *J Orthop Sports Phys Ther* 2014;44(6):391-B1.
- Frye JL, LN Ramey, JM Hart. The effects of exercise on decreasing pain and increasing function in patients with patellofemoral pain syndrome: a systematic review. *Sports health* 2012;4(3):205-10.
- Clijisen R, J Fuchs, J Taeymans. Effectiveness of exercise therapy in treatment of patients with patellofemoral pain syndrome: systematic review and meta-analysis. *Phys Ther* 2014;94(12):1697-708.
- Fukuda TY, WP Melo, BM Zaffalon, FM Rossetto, E Magalhães, FF Bryk, et al. Hip posterolateral musculature strengthening in sedentary women with patellofemoral pain syndrome: a randomized controlled clinical trial with 1-year follow-up. *J Orthop Sports Phys Ther* 2012;42(10):823-30.
- Rittweger J. Vibration as an exercise modality: how it may work, and what its potential might be. *Eur J Appl Physiol* 2010;108(5):877-904.
- Marín PJ, MR Rhea. Effects of vibration training on muscle strength: a meta-analysis. *J Strength Cond Res* 2010;24(2):548-56.
- Marín PJ, MR Rhea. Effects of vibration training on muscle power: a meta-analysis. *J Strength Cond Res* 2010;24(3):871-8.
- Anwer S, A Alghadir, H Zafar, E Al-Eisa. Effect of whole body vibration training on quadriceps muscle strength in individuals with knee osteoarthritis: a systematic review and meta-analysis. *Physiotherapy* 2016;102(2):145-51.
- Zafar H, A Alghadir, S Anwer, E Al-Eisa. Therapeutic effects of whole-body vibration training in knee osteoarthritis: a systematic review and meta-analysis. *Arch Phys Med Rehabil* 2015;96(8):1525-32.
- Wang P, X Yang, Y Yang, L Yang, Y Zhou, C Liu, et al. Effects of whole body vibration on pain, stiffness and physical functions in patients with knee osteoarthritis: a systematic review and meta-analysis. *Clin Rehabil* 2015;29(10):939-51.
- Li X, X-Q Wang, B-L Chen, L-Y Huang, Y Liu. Whole-body vibration exercise for knee osteoarthritis: a systematic review and meta-analysis. *Evid Based Complement Alternat Med* 2015;2015:758147.
- Cardinale M, C Bosco. The use of vibration as an exercise intervention. *Exerc Sport Sci Rev* 2003;31(1):3-7.
- Pérez-Turpin JA, P Zmijewski, JM Jimenez-Olmedo, M Jové-Tossi, A Martínez-Carbonell, C Suárez-Llorca, et al. Effects of whole body vibration on strength and jumping performance in volleyball and beach volleyball players. *Biology of sport* 2014;31(3):239.
- Roelants M, C Delecluse, SM Verschueren. Whole-body-vibration training increases knee-extension strength and speed of movement in older women. *Journal of the American Geriatrics Society* 2004;52(6):901-8.
- Kvorning T, M Bagger, P Caserotti, K Madsen. Effects of vibration and resistance training on neuromuscular and hormonal measures. *Eur J Appl Physiol* 2006; 96(5):615-25.
- Preatoni E, A Colombo, M Verga, C Galvani, M Faina, R Rodano, et al. The effects of whole-body vibration in

- isolation or combined with strength training in female athletes. *J Strength Cond Res* 2012;26(9):2495-506.
28. Bertuzzi R, LA Pasqua, S Bueno, MV Damasceno, AE Lima-Silva, D Bishop, et al. Strength-training with whole-body vibration in long-distance runners: a randomized trial. *Int J Sports Med* 2013;34(10):917-23.
 29. Magalhães E, Fukuda TY, Sacramento SN, Forgas A, Cohen M, Abdalla RJ. A comparison of hip strength between sedentary females with and without patellofemoral pain syndrome. *J Orthop Sports Phys Ther* 2010;40(10):641-7.
 30. Nijs J, C Van Geel, B Van de Velde. Diagnostic value of five clinical tests in patellofemoral pain syndrome. *Man Ther* 2006;11(1):69-77.
 31. van Linschoten R, M van Middelkoop, MY Berger, EM Heintjes, JA Verhaar, SP Willemsen, et al. Supervised exercise therapy versus usual care for patellofemoral pain syndrome: an open label randomised controlled trial. *BMJ* 2009;339:b4074.
 32. Osugi T, J Iwamoto, M Yamazaki, M Takakuwa. Effect of a combination of whole body vibration exercise and squat training on body balance, muscle power, and walking ability in the elderly. *Ther Clin Risk Manag* 2014;10:131-8.
 33. Kim Y-Y, S-E Park. Comparison of whole-body vibration exercise and plyometric exercise to improve isokinetic muscular strength, jumping performance and balance of female volleyball players. *J Phys Ther Sci* 2016; 28(11):3140.
 34. Bush JA, GL Blog, J Kang, AD Faigenbaum, NA Ratamess. Effects of quadriceps strength after static and dynamic whole-body vibration exercise. *J Strength Cond Res* 2015;29(5):1367-77.
 35. Munera M, WBertucci, SDuc, XChieimentin. Transmission of whole body vibration to the lower body in static and dynamic half-squat exercises. *Sports Biomech* 2016; 15(4):409-28.
 36. Rauch F, H Sievanen, S Boonen, M Cardinale, H Degens, D Felsenberg, et al. Reporting whole-body vibration intervention studies: recommendations of the International Society of Musculoskeletal and Neuronal Interactions. *J Musculoskelet Neuronal Interact* 2010; 10(3):193-8.
 37. Chesworth BM, EG Culham, GE Tata, M Peat. Validation of outcome measures in patients with patellofemoral syndrome. *J Orthop Sports Phys Ther* 1989; 10(8):302-8.
 38. Crossley KM, KL Bennell, SM Cowan, S Green. Analysis of outcome measures for persons with patellofemoral pain: which are reliable and valid? *Arch Phys Med Rehabil* 2004;85(5):815-22.
 39. Kuru T, EE Dereli, A Yaliman. Validity of the Turkish version of the Kujala patellofemoral score in patellofemoral pain syndrome. *Acta Orthop Traumatol Turc* 2010;44(2):152-6.
 40. Kujala UM, LH Jaakkola, SK Koskinen, S Taimela, M Hurme, O Nelimarkka. Scoring of patellofemoral disorders. *Arthroscopy* 1993;9(2):159-63.
 41. Crossley K, K Bennell, S Green, S Cowan, J McConnell. Physical therapy for patellofemoral pain a randomized, double-blinded, placebo-controlled trial. *Am J Sports Med* 2002;30(6):857-65.
 42. Ware Jr JE, CD Sherbourne. The MOS 36-item short-form health survey (SF-36): I. Conceptual framework and item selection. *Med Care* 1992:473-83.
 43. Demiral Y, G Ergor, B Unal, S Semin, Y Akvardar, B Kivircik, et al. Normative data and discriminative properties of short form 36 (SF-36) in Turkish urban population. *BMC Public Health* 2006;6(1):1.
 44. Delecluse C, M Roelants, S Verschueren. Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc* 2003; 35(6):1033-41.
 45. Osawa Y, Y Oguma, N Ishii. The effects of whole-body vibration on muscle strength and power: a meta-analysis. *J Musculoskelet Neuronal Interact* 2013;13(3):380-90.
 46. Rogan S, ED de Bruin, L Radlinger, C Joehr, C Wyss, N-J Stuck, et al. Effects of whole-body vibration on proxies of muscle strength in old adults: a systematic review and meta-analysis on the role of physical capacity level. *Eur Rev Aging Phys Act* 2015;12(1):12.
 47. Luo J, B McNamara, K Moran. The use of vibration training to enhance muscle strength and power. *Sports Med* 2005;35(1):23-41.
 48. Maffiuletti NA, J Saugy, M Cardinale, J-P Micallef, N Place. Neuromuscular fatigue induced by whole-body vibration exercise. *Eur J Appl Physiol* 2013; 113(6):1625-34.
 49. Powers CM. Rehabilitation of patellofemoral joint disorders: a critical review. *J Orthop Sports Phys Ther* 1998;28(5):345-54.
 50. Cardinale M, J Lim. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *J Strength Cond Res* 2003;17(3):621-4.
 51. Feland J, M Hawks, J Hopkins, I Hunter, A Johnson, D Eggett. Whole body vibration as an adjunct to static stretching. *Int J Sports Med* 2010;31(08):584-9.
 52. Bokaeian HR, AH Bakhtiary, M Mirmohammadkhani, J Moghimi. The effect of adding whole body vibration training to strengthening training in the treatment of knee osteoarthritis: A randomized clinical trial. *J Bodyw Mov Ther* 2016;20(2):334-40.
 53. Karatrantou K, V Gerodimos, K Dipla, A Zafeiridis. Whole-body vibration training improves flexibility, strength profile of knee flexors, and hamstrings-to-quadriceps strength ratio in females. *J Sci Med Sport* 2013;16(5):477-81.
 54. Yu CH, SB Seo, SR Kang, K Kim, TK Kwon. Effect of vibration on muscle strength imbalance in lower extremity using multi-control whole body vibration platform. *Biomed Mater Eng* 2015;26(s1):S673-S83.
 55. Kim J, Y Park, Y Seo, G Kang, S Park, H Cho, et al. The effects of whole-body vibration exercise on isokinetic muscular function of the knee and jump performance

- depending on squatting position. *J Phys Ther Sci* 2016;28(1):159-61.
56. Lee S-H, J-H Lee, S-E Ahn, M-J Park, D-H Lee. Correlation between quadriceps endurance and adduction moment in medial knee osteoarthritis. *PloS one* 2015;10(11):e0141972.
57. Bruyere O, M-A Wuidart, E Di Palma, M Gourlay, O Ethgen, F Richy, et al. Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. *Arch Phys Med Rehabil* 2005;86(2):303-7.
58. Álvarez-Barbosa F, J del Pozo-Cruz, B del Pozo-Cruz, RM Alfonso-Rosa, ME Rogers, Y Zhang. Effects of supervised whole body vibration exercise on fall risk factors, functional dependence and health-related quality of life in nursing home residents aged 80+. *Maturitas* 2014;79(4):456-63.
59. Furness TP, WE Maschette. Influence of whole body vibration platform frequency on neuromuscular performance of community-dwelling older adults. *J Strength Cond Res* 2009;23(5):1508-13.
60. Moretti E, A Tenório, L Holanda, A Campos, A Lemos. Efficacy of the whole-body vibration for pain, fatigue and quality of life in women with fibromyalgia: A systematic review. *Disabil Rehabil* 2018;40(9):988-96.
61. Wang P, L Yang, C Liu, X Wei, X Yang, Y Zhou, et al. Effects of whole body vibration exercise associated with quadriceps resistance exercise on functioning and quality of life in patients with knee osteoarthritis: a randomized controlled trial. *Clin Rehabil* 2016; 30(11):1074-87.