Effect of whole body vibration exercise on muscle strength and proprioception in females with knee osteoarthritis

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ABSTRACT

The purpose of this study was to assess the effect of whole body vibration (WBV) exercise on muscle strength and proprioception in female patients with osteoarthritis in the knee (knee-OA). A single blinded, randomised, controlled trial was performed in an outpatient clinic on 52 female patients diagnosed with knee-OA (mean age 60.4 years ± 9.6). They were randomly assigned to one of 3 groups: 1. WBV-exercise on a stable platform (VibM; $n = 17$ (mean age, 61.5 ± 9.2)), WBV-exercise on a balance board (VibF; $n = 18$ (mean age, 58.7 ± 11.0)), or control group (Con; $n = 18$ (mean age, 61.1 ± 8.5)).

The WBV groups trained twice a week for 8 weeks, with a progressively increasing intensity. The WBV groups performed unloaded static WBV exercise.

The following were measured: knee muscle strength (extension/flexion) and proprioception (threshold for detection of passive movement (TDPM)). Self-reported disease status was measured using WOMAC.

It was found that muscle strength increased significantly ($p < 0.001$) in VibM compared to Con. Isometric knee-extension significantly increased ($p = 0.021$) in VibM compared to Con. TDPM was significantly improved ($p = 0.033$) in VibF compared to Con, while there was a tendency ($p = 0.051$) for VibM to perform better compared to Con. There were no effects in the self-reported disease status measures.

This study showed that the WBV-exercise regime on a stable platform (VibM) yielded increased muscle strength, while the WBV-exercise on a balance board (VibF) showed improved TDPM. The WBV-exercise is a time-saving and safe method for rehabilitation of women with knee-OA.

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1. Introduction

Knee osteoarthritis (OA) is characterized by pain and impairment in body functions such as muscle strength, proprioception and joint stability [1,2]. In addition, knee OA has a major impact on physical functioning in daily life and frequently leads to moderate to severe limitations in participation [3,4].

Optimal neuromuscular function is suggested to be of critical importance to development and/or progression of knee OA [2]. Compared to healthy participants, patients with knee OA have a poorer joint position sense (JPS) and a higher threshold for detection of passive movement (TDPM), i.e. a reduced proprioceptive function of the affected joint [5–7]. Several studies and systematic reviews have clearly indicated a short term effect of exercise on pain and disability in OA patients [8,9], but this effect is not sustained in the long term [10]. However, exercise, and strength training in particular,

could be potentially damaging to the OA affected joint if the load is too high or malalignment is present [11]. Thus exercise performed within the therapeutic window where the load is high enough to have effect, but not high enough to deteriorate the osteoarthritis, would be desirable.

Whole body vibration (WBV) exercise have been shown to increase muscle strength [12–14], and several studies have shown that WBV is a time-saving, safe and effective intervention for reducing age-related decline in muscle strength and improve functional capacity [15–17]. Thus, WBV exercise could yield similar effects as regular strength training but with lower loads on the affected joint, due to low joint dynamics during exercise. In addition, WBV exercise might also improve neuromuscular performance [18,19]. WBV training has typically been applied on a stable WBV-platform, but recently a vibration platform built into a balance board has been introduced, thus increasing the demand of stabilization and postural control to the patient. The purpose of this study was to evaluate whether WBV could improve muscle strength, proprioception, decrease pain and disability on patients with knee OA. The current paper presents the effect of WBV training on muscle strength and proprioception.

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2. Materials and methods

2.1. Participants

Two-hundred and twelve women diagnosed with osteoarthritis—in one or both knees—were invited by mail to participate in the study. Sixty subjects volunteered to participate (Fig. 1). The patients were recruited from the outpatient clinic and were all otherwise healthy, without other medical diseases (e.g. diabetes mellitus, earlier neurological disease, etc.), hip, ankle, neck or back pains. Fifty-two patients (mean age: 60.4±9.6 years) (Table 1) fulfilled the ACR criteria for knee OA [20], including both clinical and radiographic signs of OA, and all patients' diagnosis of knee OA had been made from 2 to 10 years before participating in this study. The patients had mild to moderate OA, as indicated by both the Western Ontario and McMaster Universities' OA index (WOMAC) [21]. Disease duration was from 2 to 10 years. The patients were either on no medication or on stable minor pain medication, e.g. paracetamol and low-dose non-steroidal anti-inflammatory drugs not expected to influence the sensory afferent function, and none had been injected or received other invasive therapies in their joints during the preceding 3 months. Weight and height were measured during baseline measurements and body mass index (BMI: weight [kg]/height^2 [m^2]) was calculated.

The Scientific Ethics Committee for Copenhagen and Frederiksberg (J. no. KF 01-077/02) approved the experimental protocol and each participant signed an informed consent before participating in the study.

2.2. Design

The study was designed as a single blinded, randomized, controlled clinical trial. All subjects were randomly assigned to one of three interventions: 1) balance board with built-in vibration (VibF), 2) stable vibration platform (VibM) or 3) control group (Con). The randomization was envelope based, with concealed allocation until all

Table 1
Demographic data and baseline observations in the self-reported questionnaire (WOMAC), muscle strength and proprioception tests of each trial group

Characteristics	Control (n = 17)	VibF (n = 18)	VibM (n = 17)	Total (n = 52)
Age, years	61.1 ± 8.5	58.7 ± 11.0	61.5 ± 9.2	60.4 ± 9.6
Weight, kg	81.6 ± 15.4	80.0 ± 18.7	80.6 ± 14.4	80.7 ± 16.0
Height, cm	164 ± 5.3	165 ± 6.3	167 ± 5.9	165 ± 6.0
Body-mass index, kg/m^2	30.2 ± 5.4	29.1 ± 5.8	29.2 ± 6.1	29.5 ± 5.7
WOMAC, pain 0–100 mm	25.5 ± 20.7	30.9 ± 22.1	22.8 ± 16.2	26.5 ± 19.8
WOMAC, disability 0–100 mm	28.5 ± 19.0	29.5 ± 23.5	25.5 ± 18.6	27.9 ± 20.2
WOMAC, stiffness 0–100 mm	43.3 ± 30.7	36.1 ± 32.0	30.7 ± 24.5	36.6 ± 29.1
Isokinetic muscle strength				
Extension (Nm)				
30°·s^{-1}	63.8 ± 26.4	56.2 ± 28.9	69.5 ± 20.4	63.3 ± 25.4
60°·s^{-1}	60.1 ± 21.3	48.3 ± 21.7	66.1 ± 17.3	58.5 ± 21.0
90°·s^{-1}	60.1 ± 20.0	46.2 ± 21.2	65.8 ± 14.1	57.7 ± 19.9
Flexion (Nm)				
30°·s^{-1}	36.2 ± 9.8	33.8 ± 12.5	42.7 ± 12.0	37.6 ± 11.8
60°·s^{-1}	38.3 ± 8.9	36.5 ± 13.3	43.4 ± 12.5	39.5 ± 11.7
90°·s^{-1}	36.6 ± 10.2	34.7 ± 13.4	44.2 ± 10.4	38.6 ± 11.8
Isometric muscle strength				
Extension (Nm)	71.4 ± 26.4	61.1 ± 26.4	76.2 ± 17.9	69.8 ± 24.1
Flexion (Nm)	34.5 ± 12.0	31.5 ± 10.5	45.0 ± 13.4	37.1 ± 13.1
TDPM (s)	2.4 ± 1.1	3.0 ± 1.1	2.1 ± 0.8	2.5 ± 1.0

The data are presented as a mean ± SD.

baseline measurements were performed. The characteristics of the 52 subjects that completed all pre tests are given in Table 1. No significant differences in age, weight, height and BMI among all groups were detected at the start of the study (Table 1). The two intervention programs consisted of 16 training sessions within an 8-wk period. Training frequency was twice a week with at least 2 days of rest between two sessions. The control group did not participate in any training.
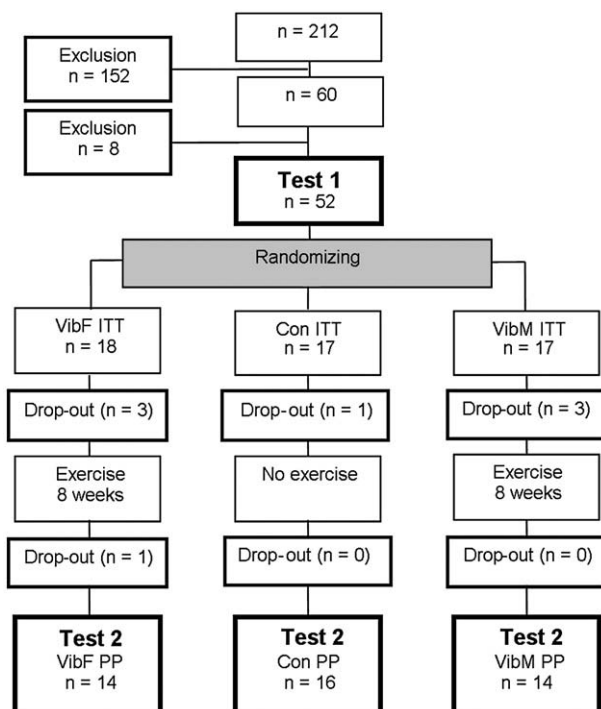
2.3. Whole body vibration training

WBV training was performed on a conventional stable WBV-platform (VibM, Xendon, Sweden) (VibM) or a balance board with a built-in vibration device (Vibrosfäre, ProMedVi, Sweden) (VibF). Both machines are applying whole-body vibration/oscillation muscle stimulation to the lower extremities. The subject stands with bent knees and hips on the platform, which oscillates with a sagittal axle, giving thrusts to the legs alternately upwards and downwards. The patients flexed their knees until a position in which they could perform the entire exercise bout without pain and fatigue. The amount of knee flexion was thus gradually progressed if the patients improved in muscle strength, endurance and/or symptoms. The neuromuscular system reacts to this vibration in a chain of rapid muscle contractions,
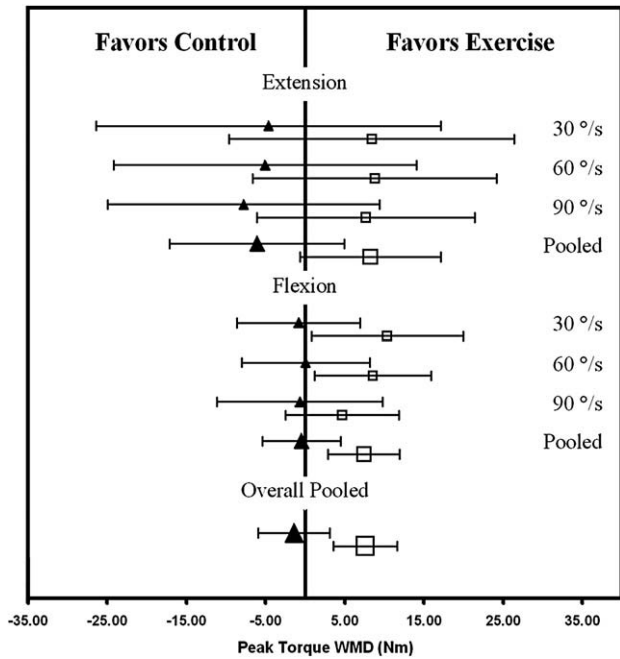

Fig. 1. Study flow chart. Test 1 is the baseline assessment. Test 2 is the assessment after 8 weeks of WBV-exercise or control. ITT: Intention to treat. PP: Per protocol.

Table 2
WBV training program and progress

Week	Day	Frequency	Time/rep.	Exercise
1	Mon	25 Hz	30 s/6	Static
	Thur	25 Hz	30 s/6	Static
2	Mon	25 Hz	40 s/6	Static
	Thur	25 Hz	40 s/6	Static
3	Mon	25 Hz	50 s/6	Static
	Thur	25 Hz	50 s/7	Static
4	Mon	25 Hz	60 s/7	Static
	Thur	25 Hz	60 s/7	Static
5	Mon	30 Hz	40 s/7	Static
	Thur	30 Hz	50 s/7	Static
6	Mon	30 Hz	50 s/8	Static
	Thur	30 Hz	50 s/8	Static
7	Mon	30 Hz	60 s/8	Static
	Thur	30 Hz	60 s/8	Static
8	Mon	30 Hz	70 s/8	Static
	Thur	30 Hz	70 s/9	Static

Fig. 2. Isokinetic peak torque pooled and overall pooled. Forest plot of isokinetic peak torque pooled for both knee extension and knee flexion and also overall pooled for both knee extension and knee flexion at angular velocities 30°/s, 60°/s and 90°/s after the training period. ▲ indicates weighted mean difference (WMD) in Nm between VibF and Con (VibF–Con). □ indicates weighted mean difference (WMD) in Nm between VibM and Con (VibM–Con). Errorbars represent SE. The results are showed both as differences between groups for each angular velocities (30°/s, 60°/s and 90°/s), and as a pooled result. Pooled results are showed as enlarged symbols. The two pooled results for each angular velocity are collected as an overall pooled result, which are showed at the bottom of the figure. Values are not adjusted for baseline.

which are in fact reflex muscle stimulation [18]. Both exercise groups were similarly instructed to undergo static WBV-training, such that the actual exercise time, intervals and intensity were identical. Training volume and intensity were low at the beginning but progressed slowly according to the overload principle. The training volume was increased systematically over the 8-week training period by increasing the number of repetitions in one session. The training intensity was increased by increasing the frequency (24 Hz–30 Hz) of the vibration or the time/rep. on the vibrating platform (Table 2). The duration of the WBV training program was a maximum of 10 1/2 min at the end of week 8. The ratio between rest and training time was 1:1. The exercise was administrated by a skilled physiotherapist. The subjects were

asked not to perform any physical training on their WBV training day or on the day of the tests. During all WBV training sessions, the training clothes and shoes was standardized. The subjects were asked to report negative side effects or adverse reactions in their training diary.

2.4. Outcomes

2.4.1. Muscle strength
Maximal voluntary muscle strength of hamstrings and the quadriceps muscles was measured by isokinetic dynamometry at 30°/s, 60°/s, and 90°/s (Biodex System 3 PRO, Biodex Medical System, NY, USA) as previously described [22].

2.4.2. Proprioception
Threshold for detection of passive movement (TDPM) was defined as the participant's ability to recognize a passive movement of the lower leg (knee extension), and was measured bilaterally. The method is previously described [23].

In short, the patients should indicate when a passive extension of the knee (1°/s) was recognized. The patients were instructed to press a button when the passive movement was recognized. The time (in milliseconds) from movement start to the button press was recorded and defined the TDPM. A reliability study of knee TDPM was performed before the actual measurements and showed an ICC (2.1) [24] of 0.87, indicating an excellent reliability.

2.4.3. Self-reported disease status
The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaire was used to evaluate level of pain, joint stiffness and functional capacity [25,26] on a 0–100 mm Visual Analogue Scale (VAS). The patients had mild to moderate OA, as indicated by baseline WOMAC (Table 1). The WOMAC scores are presented as the mean of the possible scores for each of the three sub-scales (function, pain, and stiffness).

2.5. Statistical analysis

An estimate of the necessary sample needed to detect a minimal relevant change in WOMAC pain of 20 points (SD 20), at a significance level of 0.05 and a power of 0.8 was calculated to be 17 subjects in each group [27].

The baseline data are presented as means±standard deviation (SD). The longitudinal changes (presented as mean±standard error (SE)) of the dependent variables were evaluated by 1-factor analysis of covariance (ANCOVA), with the value at baseline applied as a covariate and group allocation as a factor (with 3 levels). In case of missing data,
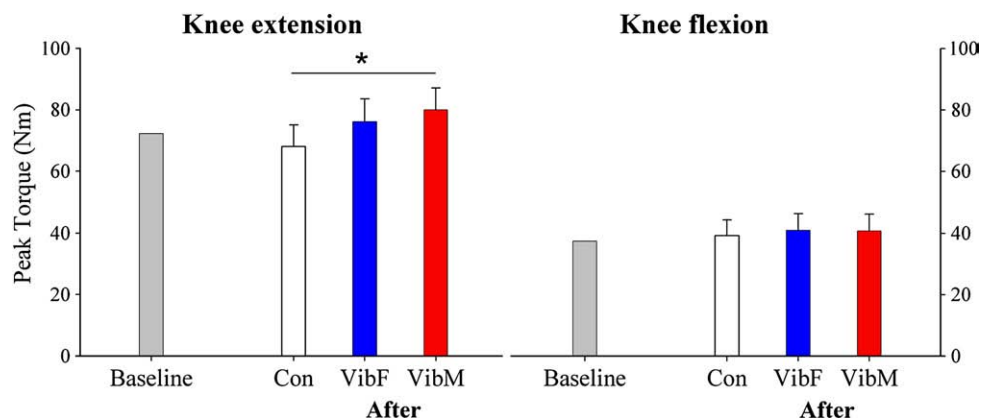
Fig. 3. Isometric knee extension and knee flexion peak torques. Baseline and follow-up average peak torques (Nm) after 8 weeks in the VibF, VibM, and Con groups. Errorbars are SE. Left: Extension. Right: Flexion. *$p=0.021$. The values are adjusted for baseline.

the baseline observation carried forward (i.e. BOCF) method was used as the intention to treat (ITT) population in the analyses; all statistical analyses were performed using the Generalized Linear Model (GLM) using SAS® statistical software (version 8; SAS institute Inc., Cary, NC, USA). The significance level was set at $P < 0.05$ (two-tailed) for all the comparisons.

2.5.1. Isokinetic muscle strength using repeated measures analysis

In order to pool the available data for isokinetic muscle strength, comparing VibF vs. Con and VibM vs. Con explicitly we applied a hierarchical model. In analogy to a meta-analysis, this can be illustrated using a forest plot, although multiple measurements on the same individual would probably violate the assumption of independence. The multiple isokinetic measurements on the same individual would be expected to be correlated. We applied a repeated-measures mixed-model with various angular velocities and directions handled as time points in the so-called Diggle model [28], which allowed interpretation on various levels of the model, as presented in Fig. 2.

3. Results

In the VibF and VibM groups, subjects got acquainted very rapidly to the exercise protocol. There were no reports of adverse side effects. During the first weeks of the study, 8 subjects dropped out (16%); 4 subjects from the VibF, 3 subjects from the VibM and 1 subject from the control group. All of these drop-outs were related to matters that had nothing to do with the training program (e.g. liver cancer (1), scheduled knee-replacement (1), uteral surgery (1), slipped disc (1), depression (1), moving to another city (1), holiday during the training period (2).

All remaining subjects of the training groups performed 16 training sessions and attended respectively 83% and 86% of the exercise sessions for VibF and VibM. The characteristics of the 44 subjects that completed all pre and post tests are given in Table 1. There were no significant differences in any of the baseline characteristics (age, weight, height, BMI, WOMAC, muscle strength and TDPM) between the WBV exercise groups and the control group (Table 1).

3.1. Isokinetic knee extension and knee flexion peak torque overall pooled

Isokinetic peak torque overall pooled, are the pooled peak torque values for both knee extension and flexion at angular velocities 30°/s, 60°/s and 90°/s. For isokinetic peak torque overall pooled we found a significant difference between VibM and Con (weighted mean difference 7.6 Nm (95% CI 3.5:11.6) $p < 0.001$) (Fig. 2), whereas no significant difference was found between VibF and Con (weighted mean difference −1.4 Nm (95% CI −5.9:3.1) $p = 0.5472$).

3.2. Isometric peak torque knee extension and knee flexion

Regarding isometric strength a significant difference was found between VibM and Con concerning knee extension (weighted mean difference 11.9 Nm (95% CI 1.9:22.0) $p = 0.021$), whereas no significant difference was found between VibF and Con (weighted mean difference 8.1 Nm (95% CI −2.3:18.4) $p = 0.1232$) (Fig. 3A). No differences were observed in knee flexion VibM and Con and VibF and Con respectively (weighted mean difference 1.6 Nm (95% CI −5.8:8.9) $p = 0.6713$ and weighted mean difference 1.8 (95% CI −5.3:8.8) $p = 0.6162$) (Fig. 3).

3.3. Proprioception

In the VibF group a significant improvement in TDPM compared to Con was found (weighted mean difference −0.59 s (95% CI −1.13:−0.05) $p = 0.0326$) (Table 3).

Table 3
Summaries of the results in self-reported questionnaire (WOMAC) and TDPM results

Per protocol	VibF vs. Con			VibM vs. Con		
	WMD	95% CI	p-value	WMD	95% CI	p-value
WOMAC pain, 0–100 mm	−6.8	(−20.1;6.6)	0.41	−1.4	(−14.6;11.9)	0.96
WOMAC disability, 0–100 mm	−2.7	(−14.8;9.4)	0.83	−1.2	(−13.3;10.9)	0.96
WOMAC stiffness, 0–100 mm	5.6	(−8.7;19.8)	0.58	1.3	(−13.2;15.9)	0.97
TDPM (s)	−0.59	(−1.13;−0.05)	0.03	−0.52	(−1.04;0.00)	0.05

The data are presented as a weighted mean difference (WMD) between groups, with 95% confidence interval (95% CI) and level of significant (p-value) after 8 wk in the VibF ($n = 13$), VibM ($n = 14$) and Con ($n = 15$) groups. The values are adjusted for baseline.
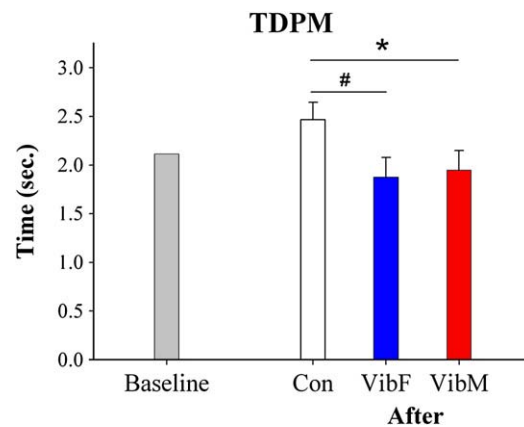
Fig. 4. Threshold for detection of passive movements (TDPM). Baseline and follow-up average TDPM values (seconds) after 8 weeks in the VibF, VibM, and Con groups. Errorbars are SE. $*p = 0.0326$; $\#p = 0.0511$. The data are adjusted for baseline.

Furthermore there was a tendency of an improved TDPM in the VibM group compared to Con (weighted mean difference −0.52 s (95% CI −1.04:0.00) $p = 0.0511$). There was no significant difference between VibF and VibM (weighted mean difference −0.07 s (95% CI −0.64:0.50) $p = 0.8052$) (Fig. 4).

3.4. Self-reported disease status

The longitudinal intra group changes from baseline to the follow-up measurement are shown in Table 3. No significant differences between groups were observed.

4. Discussion

This is the first randomized controlled trial investigating the effects of WBV-training on knee muscle strength, proprioception, and self-reported disease status, in subjects with knee-OA. The results of this study show that while knee muscle strength was significantly improved after WBV training on a stable platform (VibM) and proprioception (TDPM) improved significantly after WBV training on a vibrating balance board (VibF), no effects on self-reported disease status were observed in either group compared to the control group.

The observed effects cannot be considered as immediate training effects because the post-test measurements were performed at least 72 h after the last training session. Earlier training studies on knee-OA patients have shown significantly improved muscle strength and proprioceptive performance [12,13,29–32]. Similar findings have been reported following WBV-training studies on untrained young women and postmenopausal women [33].

The improved muscle strength in VibM found in the present study is comparable to previous results of increased muscle strength after a WBV training period [12,13,32,34]. In contrast, no increase in muscle strength after two-legged WBV training has also been reported [35], which is supported by a study that found no differences between the combination of WBV training and conventional resistance training and conventional resistance training alone [36]. The subjects in the before mentioned negative studies were young, healthy and physically active, while the subjects in our study were patients with knee-OA. This indicates that the training status is important for the outcome of the WBV training effects. As mentioned above we found significantly improved muscle strength in VibM but only a tendency in VibF. The reason for this may be due to the mixed therapeutic interventions in the VibF (balance and vibrations).

During a whole body vibration loading, skeletal muscles undergo small changes in muscle length. Vibrations elicit a response called "tonic vibration reflex", including activation of muscle spindles, mediation of the neural signals by Ia afferents, and activation of muscle fibres via large α-motor neurons. The tonic vibration reflex is also able to cause an increase in recruitment of the motor units through activation of muscle spindles and polysynaptic pathways [37]. It is well

known that the input of proprioceptive pathways (Ia, IIa and probably IIb) play an important role in the production of isometric contractions [13,32]. The increase in isometric strength after WBV training with extensive sensory stimulation might be the result of a more efficient use of the positive proprioceptive feedback loop. It may be speculated that increased muscle strength after WBV is due to neural adaptation. The exact mechanism by which muscle strength is improved is beyond the findings of this study.

Improved TDPM was only observed in the VibF group, while the VibM group showed a tendency. The statistical power (type II error) in the VibM group was 35%, and based on the present results a significant difference would require a study with 64 patients in each group [27], indicating that a type II error is likely to have occurred. Since the VibF and VibM groups received similar doses of vibrations during exercise, the proprioceptive improvement in VibF may be attributed to the balance board. To the best of our knowledge, no study has investigated the effects of WBV training on proprioception before. Studies have investigated the effect of other training types on proprioception in older women and patients with knee-OA. In a comparison between two types of training (kinaesthesia and balance training vs. resistance training) in patients with knee-OA improved joint position sense was detected in both groups, while the group that trained kinaesthesia and balance exercises had an additional improved functional capacity and motor control [33]. The results from the present study corroborate this. Earlier WBV-studies have generally used higher training doses, considering both frequency and amplitude [16,38,39], than used in the present study. Nevertheless, the data from our study suggest that even with low WBV-training doses female patient with knee-OA can improve muscle strength and neuromuscular performance.

This study shows that WBV training is a safe (no adverse effects), suitable (no drop-outs due to the intervention) and effective (increased muscle strength) training method—and potentially a feasible intervention for those patients that cannot participate in conventional strength training. The findings of this study indicate that WBV training has potential for strength gain in female patients with mild to moderate knee-OA. Additionally, WBV training could yield similar effects as regular strength training [13,32], but with lower loads on the affected joint.

The lack of effects on self-reported disease status is in contrast to earlier RCT studies, which have described effects of WBV on muscle strength, functional tasks and self reported health scores in elderly people [40–42]. Several factors may explain these different findings. Firstly, the applied WBV-exercise may not have the potential to alter physiological mechanisms to an extent that influences self-reported disease status, and the applied exercise dose may have been to low to have clinical effects of WBV-exercise. Secondly, the low number of subjects could result in a type II error. Finally, we did not measure clinical variables related to knee-OA characteristics (such as alignment, range of motion, degree of muscle wasting, radiographic grading of knee-OA), and it is possible that such characteristics may have influenced the effects of the exercise, and masked the results.

In conclusion, this is the first study that demonstrates a WBV training effect in patients with knee-OA. The findings of this study indicate that quadriceps strength, and more specifically isometric and isokinetic quadriceps strength, improves after 8 weeks of WBV training on a stable platform (VibM) in patients with knee-OA. Additionally, the data also suggest that proprioception (TDPM) may be improved after WBV training on a balance board with built in vibration (VibF). While strength and proprioceptive improvements were found, no effects in self-reported clinical effects were observed. Further research is needed to investigate the mechanism of strength gain and improved proprioception, and their relationships with clinical outcomes.

5. Conflicts of interest

None.

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