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Comparison of whole-body vibration training and quadriceps strength training on physical function and neuromuscular function of individuals with knee osteoarthritis: A randomised clinical trial

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ABSTRACT

Background: Knee osteoarthritis (KOA) is one of the leading causes of global disability, which causes knee pain, stiffness and swelling. Impaired neuromuscular function may cause joint instability, alignment changes and knee stress, which leads to the progression of KOA. Whole-body vibration (WBV) training is considered to improve pain and functional mobility effectively. However, few studies have investigated the therapeutic effect of WBV on neuromuscular function in KOA.

Material and methods: A single-blinded, randomised, controlled trial was performed on 81 participants diagnosed with KOA. The participants were randomised into three groups: (1) WBV group, in which participants performed strength training (ST) with vibration exposure for 8 weeks; (2) ST group, in which participants performed ST without vibration for 8 weeks; and (3) health education (HE) group, in which participants received a HE for 8 weeks. The visual analogue scale for knee pain, isokinetic muscle strength test, proprioception test, Timed Up and Go test (TUG) and 6-min Walk Distance test (6MWD) were performed before and after the interventions.

Results: No significant difference was found on pain, proprioception, TUG and 6MWD. A significant interaction effect was found in isokinetic muscle strength between groups. Further analysis showed that compared with the HE group, the WBV group exhibited significantly greater improvement in isokinetic muscle strength (peak torque [PT] of extensors, $p < 0.01$, 95% CI = 0.11–0.33 Nm/kg; PT of flexors, $p = 0.01$, 95% CI = 0.02–0.19 Nm/kg; peak work [PW] of extensors, $p < 0.01$, 95% CI = 0.12–0.75 W/kg). In addition, compared with the ST group, the muscle strength of the WBV group (PT of extensors, $p < 0.01$, 95% CI = 0.10–0.32 Nm/kg; PW of extensors, $p < 0.01$, 95% CI = 0.09–0.71 W/kg) improved significantly.

Conclusion: Our findings suggested that adding WBV training to ST might benefit muscle strength around the knee joint in patients with KOA.

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Background

Osteoarthritis (OA) is the most common type of arthritis and a major cause of disability; it reduces independence and leads to a poor quality of life in the aging population.¹ Amongst the joints affected by OA, the knee is the most prevalent, especially in elderly women.² Knee OA (KOA) is a degenerative, non-infectious knee joint disease and one of the leading causes of global disability.³

Individuals with KOA often suffer from arthralgia, stiffness, swelling, decreased muscle strength, impaired proprioceptive function and physical foundational limitation.^{4–6} In the US, the prevalence of symptomatic KOA has increased 12.1% in 1994 to 33.6% in 2017, with adults older than 65 years old being primarily affected.^{7,8}

As suggested by several international guidelines, non-pharmacological and pharmacological modalities (including surgical treatment) should be combined to manage KOA.^{9–11} Amongst the non-pharmacological management approaches for KOA, exercise is strongly recommended for effective treatment. Examples include aerobic and/or resistance land-based exercise, aquatic

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exercise, weight loss and Tai Chi.⁹ Amongst them, strength exercises are considered as the foundation of non-pharmacological treatments.¹²

Whole-body vibration (WBV) training is performed as a neuromuscular modality in muscle strength training (ST),¹³ and it is widely used in health management centres, local gyms and rehabilitation centres. As a safe, effective and potentially feasible treatment, WBV training has also been proposed for several musculoskeletal system diseases, such as low back pain, osteoporosis and chronic Achilles tendonitis,^{14,15} and even in patients with neurological disorders.¹⁶

Recently, WBV training has been explored for the therapeutic treatment of KOA, particularly in the aspects of pain relief and improvement in physical function.^{17–19} Several systematic reviews and meta-analyses have confirmed its therapeutic effects on pain and physical function in individuals with KOA.^{20,21} However, in relation to pain relief and self-reported improvement in physical function, Li et al. reported opposite results.²² They argued that evidence showing the positive effect of WBV in KOA was limited. At present, the effect of WBV training on pain and physical function remains uncertain.

The symptoms of KOA have negative effects on neuromuscular function. For example, swelling of the knee joint has been reported to affect muscle strength and proprioception.^{23,24} Although there is currently no direct evidence linking impaired proprioception accuracy or weak muscles around the knee joint in the development or progression of KOA, several studies have shown that decreased muscle strength and poor proprioception might be associated with knee pain²³, increased activity limitations²⁵ and systemic inflammation²⁶ in KOA.

Furthermore, few studies have evaluated the therapeutic effect of WBV training on neuromuscular function in individuals with KOA. Trans et al.²⁷ found that two kinds of WBV training regimes (different vibration platforms) improved the isokinetic strength of knee extensors and threshold for the detection of passive knee extension but not the self-reported knee pain and function in women with KOA. Segal et al.²⁸ conducted a randomised controlled study to determine the effect of vibration training on proprioception, muscle strength and power in women with KOA risk factors. However, no significant difference was observed amongst all outcomes between groups. Similarly, previous studies that focused on muscle strength failed to find consistent results.^{17,29,30} These inconsistent results of previous studies hinder the validation of the effects of WBV training on neuromuscular function in patients with KOA.

The present study aimed to investigate the therapeutic effect of WBV training on the neuromuscular function of patients with KOA. We conducted a single-blind randomised controlled trial to determine the efficacy of an 8-week WBV training programme compared with lower extremity ST and health education (HE) on muscle strength and proprioception in individuals with KOA. We hypothesised that WBV training would induce an effect similar to that of ST, that is, increased muscle strength and improved proprioception in KOA.

Materials and methods

This single-blind randomised controlled trial was conducted at the Sport Medicine and Rehabilitation Centre, Shanghai University of Sport. The study was approved by the Ethics Committee of Shanghai University of Sport (Ref. No: 2016–016) and registered at the Chinese Clinical Trial Registry a priori as a clinical trial (ID: ChiCTR-IOR-16009234).

Participants

With settings of $\alpha = 0.05$, power $(1 - \beta) = 0.80$ and effect size = 0.25 for two-tailed test, power analysis showed that three independent groups with 81 participants in total were the required sample size. In this study, the training of participants focused on enhancing the muscles around the knee joint. Therefore, the strength of knee flexors and extensors was considered as the primary outcome. According to Tsuji's study, the effect size of WBV training on strength improvement for KOA was 0.21–0.48.¹⁸ The effect size ($d = 0.25$) was used to estimate the sample size, which was commonly used in sample size calculation.

KOA patients were recruited via posters in community centres in Shanghai, China. The diagnosis of KOA was performed by an orthopaedic surgeon based on the patients' medical history, X-ray imaging and physical assessment. The inclusion criteria were as follows: (1) men or women with radiographic diagnostic criteria of definite KOA (unilateral or bilateral) and who reported pain for at least 3 months; (2) mild-to-moderate KOA (Lequesne knee score = 1–7); (3) aged 50–70 years old; (4) medication not expected to change during the study period; and (5) available three times a week for over 3 months. The exclusion criteria were as follows: (1) had undergone knee surgery in the past 6 months; (2) had acute symptomatic KOA; (3) had muscular, joint or neurological conditions that affect lower limb function; (4) was conducting a structured exercise programme specifically for KOA during this study period; (5) unable to understand the study's procedure; and (6) had motor neuron disorders, such as Alzheimer's and Parkinson's diseases.¹⁷

After screening, 81 eligible participants were informed about the study procedures and given written informed consent in advance. These participants were randomly allocated into three groups, namely, WBV group, ST group and HE group. The randomisation sequence was created by the main investigator (LW) using computer-generated randomisation. Furthermore, opaque envelopes containing the groupings of participants, which were blinded to the researchers, were used for randomisation.

Outcome measures

Before the intervention, the demographic data was collected, including sex, age, body mass index, Lequesne knee score, affected side and medication compliance. The outcome measurements were conducted before and after the interventions. Furthermore, the researchers were blinded to the group allocation.

Isokinetic muscle strength

Extensor and flexor strength of the affected or worst side was measured using an isokinetic dynamometer (Physiomed, CONTREX, TP 1000, Germany). The participants were instructed to perform a 5-min warm-up and familiarise themselves with the test procedure in advance. The researchers secured the participants to the dynamometer with straps. In the formal test, the maximal concentric knee extension–flexion contractions were performed at angular velocities of 90 and 180°/s. The work was recorded from 80° to 10° of knee moving angle, and 0° was considered as the full extension. The tests at angular velocities of 90 and 180°/s consisted of ten repetitions with a 5-min rest period between each set. The peak torque and peak work were used for statistical analysis. In isokinetic muscle strength tests, several velocities, including 60 or 90°/s for maximal contraction test and 120 or 180°/s for muscle endurance test were selected in accordance with a previous experiment from our laboratory and previous studies.^{19,31,32} However, previous studies showed that slower isokinetic angular

velocities mechanically overload the knee, irritating the joint and exacerbating symptoms. Consequently, we used 90 and 180°/s velocities in this study, which were also commonly used for elderly and KOA.³³ The participants were encouraged to move as forcefully as possible. The peak torque (PT, Nm/kg) and peak work (PW, W/kg) normalised by body mass were recorded for analysis.

Proprioception of the knee

Position sense (joint angle replication task) and motion sense (detection task of passive movement) were commonly used to evaluate proprioception. According to the study of Hannah, the position sense of the knee joint did not improve significantly after WBV training.³⁴ Therefore, the proprioception of the knee was observed as the threshold to detection of a passive movement (TDPM), whose test details have been reported in our previous study.³⁵ TDPM was tested using an electrically driven movable frame whilst the participants were isolated to reduce any auditory or visual interference. After adjusting the sitting position and knee joint angle, the plane moved the shank forward or backward. Participants would stop the plane immediately when they perceived the movement. The rotation angles of the frame were determined as TDPM of knee flexion and extension. The mean value of three successful trials was used for analysis.

Physical function and knee pain

The Timed Up and Go test (TUG) and 6-min Walk Distance test (6MWD) were used to determine function performance. These methods are simple and reliable measurements which have been used commonly.^{17,36} The average values of three successful trials were calculated.

The self-reported pain was evaluated using a 10-cm visual analogue scale (VAS; 0 cm, no pain; 10 cm, maximal pain). The participants were asked to recall knee pain related to knee joint movement in the previous week and mark on the line.

Intervention

A certified physical therapist supervised the interventions in the WBV, ST and HE groups according to the procedure. Each training session comprised a 5-min warm-up and 5-min cooldown, which consisted of joint motion and muscle stretch. The physical therapist monitored the angle of knee flexion quantitatively with a goniometer throughout each session of WBV and ST.

WBV training group

Participants in the WBV group performed the training 3 days per week for 8 weeks. The training was conducted on a vertical vibration device (i-vib5050; Sport Platform, China). As shown in Fig. 1, during the training, the participants performed static squat training barefoot on the platform with bent knees (30° and 60°). The distance between the feet was consistent with the shoulders. As shown in Table 1, the duration time, sets and total time were increased progressively over the 8-week training period on the basis of a previous study, which improved the muscle strength and proprioception.²⁷ The parameters of WBV were set at a frequency of 20 Hz and amplitude of 2 mm.

ST group

The ST group performed three training sessions per week for 8 weeks under supervision similar to the WBV group. The only difference between the two training regimens of the WBV and ST



Fig. 1. The whole-body vibration training with bent knee (60° and 30°).

groups was that WBV training was conducted on a vibration platform, whereas ST was conducted on flat ground. The protocol of ST, including the duration time and angle of the bent knee, was similar to WBV training except for the vibration exposure (Table 1).

HE group

The participants in the HE group received 8 weeks of HE. They attended one 60-min group session per week. The HE sessions consisted mainly of educational information including understanding KOA, risk factors associated with KOA, pain management and recommended treatment options. Furthermore, the participants in the HE group were required to maintain their previous lifestyle and not attend any other regular rehabilitation programmes during the study period.

Statistical analysis

The data were included in the analysis of all participants, and intention-to-treat analysis was utilised. For participants who withdrew from the study, the missing values were replaced with the last assessment score. One-way analysis of variance (ANOVA) and chi-squared test were performed to determine the difference of demographic characteristics and baseline values amongst groups. The two-way (time*groups) repeated measures ANOVA was used to determine the difference in outcomes amongst the three groups. The effect size of between-group effect was calculated by partial eta-squared. Significance was set at $p < 0.05$. For post hoc test, the difference of each index relative to baseline was calculated, and one-way ANOVA was used for pairwise comparison. For post hoc one-way ANOVA, the significance was corrected at $p < 0.017$.

Results

Participants

In this study, 81 participants were included for data analysis with 27 participants in each group. In addition, 17 participants dropped out during the interventions (5 in the WBV group, 4 in the ST group and 8 in the HE group). The main reasons for withdrawal were as follows: 1) loss of interest, 2) long distance to the rehabilitation centre and 3) other diseases not related to the interventions in this study. These reasons were equally distributed

Table 1
The protocol of training in WBV and ST group.

Week of intervention	Knee flexion angle	Hold time	Rest time	Number of set	Total time
1	30°	30s	30s	6	12 min
	60°	30s	30s	6	
2	30°	40s	40s	6	14 min
	60°	30s	30s	6	
3	30°	40s	40s	7	17 min
	60°	40s	40s	6	
4	30°	50s	50s	7	21 min
	60°	40s	40s	7	
5	30°	50s	50s	8	25 min
	60°	50s	50s	7	
6	30°	60s	60s	8	29 min
	60°	50s	50s	8	
7	30°	60s	60s	9	34 min
	60°	60s	60s	8	
8	30°	70s	70s	9	39 min
	60°	60s	60s	9	

ST, strength training; WBV, whole body vibration.

amongst these groups.

The demographic characteristics of participants are shown in Table 2. The age (63.67 ± 4.84 years, HE group; 64.81 ± 4.04 years, ST group; 63.52 ± 4.98 years, WBV group), height (157.76 ± 5.10 cm, HE group; 158.89 ± 6.06 cm, ST group; 160.16 ± 7.66 cm, WBV group) and weight (58.25 ± 7.02 kg, HE group; 58.36 ± 8.60 kg, ST group; 62.32 ± 8.48 kg, WBV group) was parallel in the three groups. No significant difference in baseline data was observed amongst the groups, thereby confirming the baseline homogeneity of the groups.

Isokinetic muscle strength

As shown in Fig. 2, no significant between-group effect of most strength variables in $90^\circ/s$ was found ($p > 0.05$, between-subject). Furthermore, at $90^\circ/s$, a significant interaction effect in PW of knee flexors was found ($p < 0.05$, $\eta^2 = 0.09$, interaction). However, the following post hoc test showed no significant difference in the PW of knee flexors amongst the WBV, ST and HE groups ($F = 3.93$, $p = 0.02$).

As for the outcomes at $180^\circ/s$, no significant between-group effect was detected for most isokinetic muscle strength ($p > 0.05$, between-subject) (Fig. 3). A significant interaction effect was found in the PT of extensors ($p < 0.01$, $\eta^2 = 0.276$, interaction), PT of flexors ($p < 0.05$, $\eta^2 = 0.112$, interaction) and PW of extensors ($p < 0.05$, $\eta^2 = 0.151$, interaction). Moreover, the post hoc test showed that these three outcomes were significantly increased in the WBV group compared with the HE group (PT of extensors, mean difference = 0.22 ± 0.05 Nm/kg, $p < 0.01$, 95% CI = $0.11-0.33$ Nm/kg; PT of flexors, mean difference = 0.11 ± 0.04 Nm/kg, $p = 0.01$, 95% CI = $0.02-0.19$ Nm/kg; PW of extensors, mean

difference = 0.43 ± 0.13 W/kg, $p < 0.01$, 95% CI = $0.12-0.75$ W/kg). Compared with the ST group, the PT and PW of knee extensors were significantly improved in the WBV group (PT of extensors, mean difference = 0.21 ± 0.05 Nm/kg, $p < 0.01$, 95% CI = $0.10-0.32$ Nm/kg; PW of extensors, mean difference = 0.40 ± 0.13 W/kg, $p < 0.01$, 95% CI = $0.08-0.71$ W/kg).

Proprioception

After 8-week WBV, ST or HE intervention, no significant difference among groups was found in knee flexion ($p = 0.02$, within-subject; $p = 0.15$, interaction; $p = 0.54$, between-subject) and knee extension ($p = 0.18$, within-subject; $p = 0.07$, interaction; $p = 0.70$, between-subject).

Physical function and knee pain

No significant difference among WBV, ST and HE groups was observed in TUG ($p < 0.01$, within-subject; $p = 0.05$, interaction; $p = 0.89$, between-subject), 6MWD ($p = 0.08$, within-subject; $p = 0.05$, interaction; $p = 0.39$, between-subject) and VAS ($p < 0.01$, within-subject; $p = 0.63$, interaction; $p = 0.77$, between-subject).

Discussion

The results showed that the 8-week WBV training effectively increased isokinetic strength of knee extensors compared with ST or HE. In addition, the three interventions led to a similar positive effect in physical function improvement. According to previous studies, the muscle strength around the knee joint is related to the

Table 2
Demographic characteristics of participants before intervention.

Variable	HE (n = 27)	ST (n = 27)	WBV (n = 27)	P value
Age (y)	63.67 ± 4.84	64.81 ± 4.04	63.52 ± 4.98	0.534
Height (cm)	157.76 ± 5.10	158.89 ± 6.06	160.16 ± 7.66	0.389
Weight (kg)	58.25 ± 7.02	58.36 ± 8.60	62.32 ± 8.48	0.114
BMI (kg/m^2)	23.45 ± 2.99	23.08 ± 2.91	24.28 ± 2.70	0.292
Sex, M/F, (n)	4/23	2/25	5/22	0.479
Affected side, L/R, (n)	8/19	6/21	8/19	0.618
Lequesne & Mery index ^a	16/11/0/0/0	19/8/0/0/0	18/9/0/0/0	0.682
Taking NSAIDs n (%)	1 (3.7%)	2 (7.4%)	1 (3.7%)	0.769

HE, health education; ST, strength training; WBV, whole body vibration; All the data were expressed as means \pm SD.

^a Disease severity: mild/moderate/severe/very severe/extremely severe.

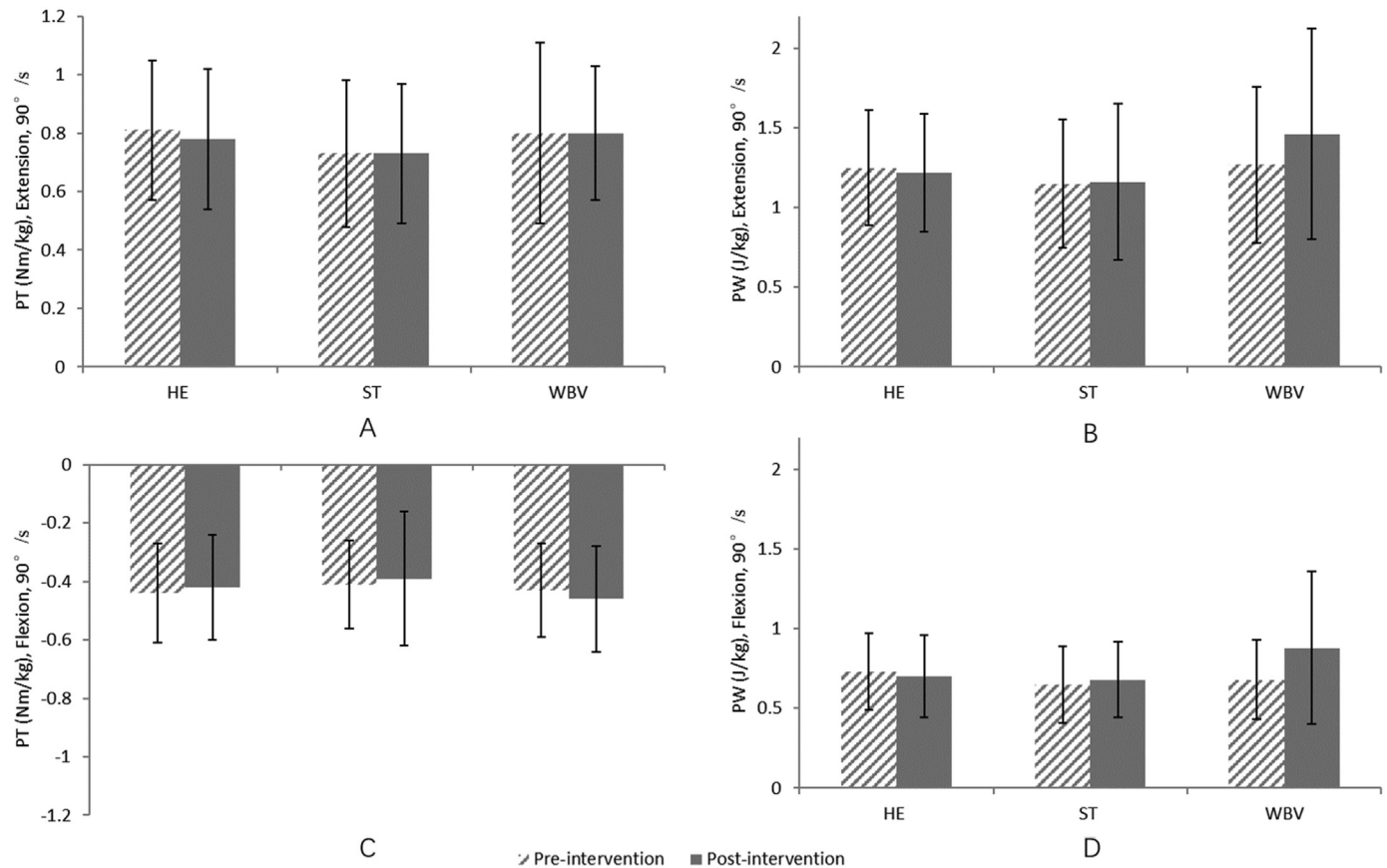


Fig. 2. Changes in isokinetic muscle strength parameters at an angular velocity of 90°/s. The changes of the peak torque of knee extensor (A), the peak work of knee extensor (B), the peak torque of knee flexor (C) and the peak work of knee flexor (D) among groups. HE, health education group; ST, strength training group; WBV, whole body vibration group; PT, peak torque; PW, peak power.

increased risk of KOA, especially quadriceps (knee extensor).^{25,33} This modality might be considered as an alternative treatment for muscle weakness in KOA. To avoid exacerbation of symptoms in KOA patients in the acute phase, those acute KOA patients were excluded in this study. Therefore, the current study findings may not be applicable to the acute symptomatic KOA.

Muscle strength

Several studies have shown that impaired neuromuscular function, such as muscle strength of the affected knee joint, might play a vital role in KOA progression.^{6,37} Although there is no evidence showing the protective role of stronger knee muscle against the onset or progression of KOA, the mass and strength of muscles around the knee joint are associated with the symptoms, prevalence and progression of KOA.^{38–40} The weakness of muscles around the knee would contribute to joint instability, which would change the alignment and stress of the knee, thereby accelerating KOA progression.⁴¹

With lower load on the affected joint, several researchers considered WBV training as an alternative intervention that could yield effects similar to those of regular ST.^{17,27} Recently, as an additional or substitute method to conventional training, WBV has been recommended for ST in elderly people and several musculoskeletal system diseases.^{14,15,42} In our study, compared with similar strength training and health education, WBV training significantly increased the muscle strength in KOA. Several reasons can explain the increased effect of WBV training on muscle strength. Firstly,

during WBV, the body of an individual is exposed to mechanical stimulation whilst standing on the oscillating platforms; stimuli are then transmitted to the primary endings of the muscle spindles. The length of the muscle–tendon complex in the skeletal muscle changes, and vibration elicits the ‘tonic vibration reflex’, which is one kind of muscle response produced by the activation of muscle spindles, mediation of Ia afferents and activation of muscle fibres.^{29,43} Secondly, during the ST, the force depends on the mass and gravity acceleration. However, for the participants in the WBV group, the acceleration was changed by the platform’s vibration, which adjusted the resistance during training sessions and might benefit the muscle strength.

Neuromuscular modulation is also involved in the possible mechanism underlying strength gain, such as increased recruitment, synchronisation, muscular coordination and proprioception.⁴⁴ In our study, the results failed to support the enhancement of proprioception by WBV. However, considering the lack of electromyography data, whether the recruitment, synchronisation and coordination of muscles around the knee joint were enhanced could not be confirmed.

Currently, there is no consensus on the effect of WBV training on muscle strength in KOA.^{19,29,43,45} Due to the absence of guidelines for optimal protocols, previous studies employed different parameters of WBV training, such as frequency, amplitude, duration, posture and even vibration device. As mentioned previously, the magnitude of provoked tonic vibration reflex is related to the protocol of WBV training, including the frequency, displacement, initial position applied in WBV training and vibration type.⁴⁵ The

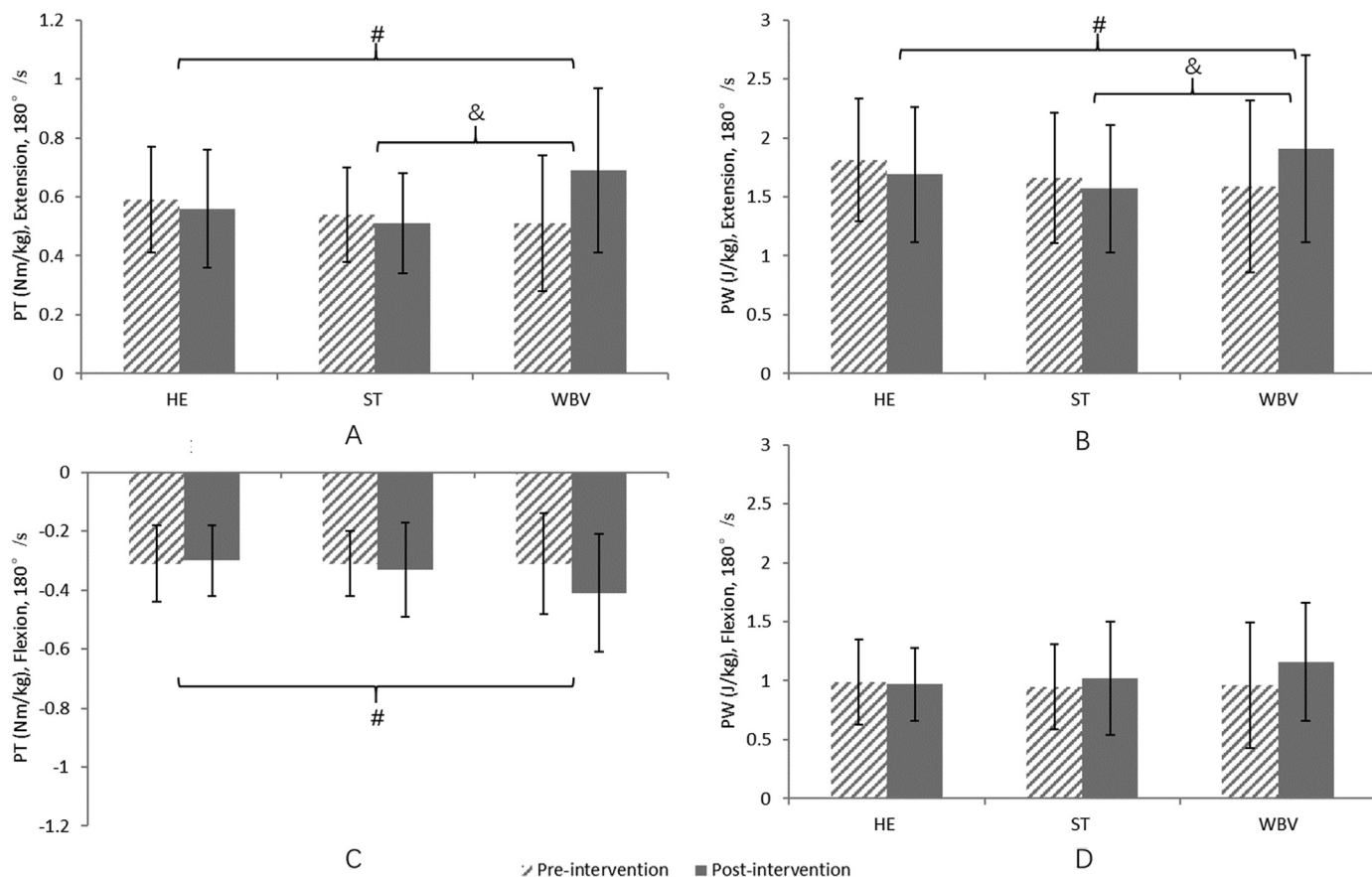


Fig. 3. Changes in isokinetic muscle strength parameters at angular velocity of 180°/s. The changes of the peak torque of knee extensor (A), the peak work of knee extensor (B), the peak torque of knee flexor (C) and the peak work of knee flexor (D) among groups. HE, health education group; ST, strength training group; WBV, whole body vibration group; PT, peak torque; PW, peak power; #, $p < 0.017$, changed significantly compared with the HE group; &, $p < 0.017$, changed significantly compared the ST group.

difference between these parameters employed might be responsible for the inconsistent conclusions.

Proprioception

The proprioception of the affected knee joint has been reportedly impaired significantly in KOA compared with age-matched controls⁶ and even non-symptomatic knee.⁴⁶ The potential association between impaired proprioception of the knee and pathological changes during the early stages of KOA has been suggested.⁴⁷ As a neuromuscular modality, WBV training was speculated to help improve proprioception and neuromuscular responses.¹³

To date, few studies have investigated the effect of WBV training on proprioception in KOA.^{27,28,34} In our study, the results showed that an 8-week WBV training did not yield significant advantage over knee proprioception improvement. The inconsistent conclusions in previous studies might be attributed to the types of vibration equipment or testing methods used for proprioception. The whole-body vibration training equipment are mainly divided into two types. Typically, WBV training has been applied on a stable platform named vertical vibration, and the platform moves straight up and down. In addition, another type named vertical alternate vibration is also commonly applied, and the motor drives a toggle mechanism that elevates one side of the platform, then the other side. In the study of Trans,²⁷ they compared the effects of two different types of vibration training devices and found that TDPM

was improved in the balance-vibration group but not in the conventional stable-vibration group. The stable WBV device (vertical platform) was applied in our study, which might contribute to the ineffectiveness in TDMP which used in our study. Moreover, in another type of proprioception, Segal collected the vibration perception threshold of the lower extremities,²⁸ and similar to our experiment, positive results were not found.

Physical function and pain

Most studies using WBV to treat KOA focused on the therapeutic effect on pain intensity, self-reported function, mobility and physical functional test.^{18,20–22,28,48} However, evidence on the effectiveness of WBV for pain relief and physical function still remains ambiguous in several systematic reviews.^{20–22} Our study found no additional improvement of WBV training on knee pain and physical functional test, which was supported by previous studies.^{18,28,48} Several factors were speculated to be associated with these outcomes of physical function, such as balance, mobility, muscle strength and flexibility. In this study, although the increased knee muscle strength was found in WBV training group, other factors might contribute to the undifferentiated results of TUG and 6MWD used to evaluate functional mobility. After WBV training with longer or more frequent interventions, the physical function of patients improved significantly compared with those who underwent a similar training.^{17,30,48} Therefore, we speculated that prolonged WBV training might promote functional improvement.

This study had several limitations. Firstly, we did not address the WBV parameters, such as frequency, displacement and type. Secondly, other factors associated with KOA, including education level and psychological factors, were not measured in this study. There is one important consideration for future studies. The participants recruited were equal to the sample size calculation, and the new participants were not recruited after some participants withdrew from the study. This might hinder the therapeutic effect of the intervention. In addition, 17 participants dropped out during the study due to their personal reasons such as long distance to the rehabilitation centre, which led to high drop-out rate. The interventions should be conducted in community centres in future clinical study to improve the adherence. Finally, a full exploration of the effect of WBV training on KOA was not possible due to the lack of analysis of disease-related biochemical indicators and neuromuscular response.

Conclusions

The present study showed the advantage of WBV training on muscle strength gain in patients with KOA compared with similar strength training without vibration and health education. Therefore, WBV training may be an effective intervention to improve knee muscle strength for the KOA patients. In the management of patients with KOA, WBV may increase muscle strength and be an effective additional treatment option in the rehabilitation programme for KOA.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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