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The Effects of Whole-Body Vibration Training for Rehabilitation After ACL Reconstruction: A Systematic Review

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Abstract

We investigated the effects of short-term WBVT program for rehabilitation after ACL reconstruction on postural control, knee position sense, and knee laxity. This review was restricted to randomized controlled trials, which investigated the rehabilitation effects of WBVT on physical function compared with conventional rehabilitation program. Data from a total of 99 participants with ACL reconstruction in 3 studies were included. Articles with high risk of bias were included based on the criteria of Cochrane Review Guideline. Furthermore, based on the International Society of Musculoskeletal and Neuronal Interactions recommendation, the lack of information on the WBV settings was found in them. Meta-analysis showed that, after WBVT intervention, no significant standardized mean difference (SMD) was observed in postural stability (n = 3; -0.58[-1.32-0.16], p = 0.13) with large heterogeneity (I^2 = 67%) and knee laxity (n = 2; -0.10[-0.50-0.70], p = 0.74) with no heterogeneity (I^2 = 0%), whereas a significant SMD was observed in position sense (n = 2; SMD = -1.44[-2.22- -0.67],p = 0.0003) with large heterogeneity (I^2 = 85%). We concluded that WBVT might be a promising alternative exercise therapy for rehabilitation after ACL reconstruction. However, to clarify the effects of WBVT on prevention from re-injury after returning to sports activities, future studies with longer term WBVT with better quality are strongly needed.

Keywords

Vibration, Exercise Therapy, Balance, Proprioception, Review

Introduction

Anterior cruciate ligament (ACL) injuries frequently occur during sports activities [1]. After the ACL reconstruction, rehabilitation programs play a key role in returning to sports. Although, to date, optimal rehabilitation program is not established, the review by van Grinsven et al. [2] indicated that the time to returning to sports would depend on the rehabilitation program.

Whole-body vibration training (WBVT) has recently been introduced in fitness clubs, clinics and professional sports teams as an alternative or supplementary to conventional training. While a vibration source can be directly applied to the muscle belly or tendon of target muscles in locally applied vibration, vibration can be indirectly applied to the target muscles by first transmitting vibration through a body part in WBVT. Because quite a few studies have widely investigated the effects of WBVT on physical function or morphological characteristics in healthy subjects including older individuals without any serious side effects, the effects of WBVT as an exercise therapy on physical function have more recently been investigated in patients with various diseases such as Parkinson disease, post stroke, cerebral palsy, muscular dystrophy, and myofibrosis [3-5].

WBVT has four unique characteristics. First, physically, the force generated by a vibration platform becomes workload in an exercise program with WBV [6]. Second, during exposure to vibration, the Ia afferent neural pathways from muscle spindles are more sensitive to vibration than other afferent neurons, such as group II afferent neurons and Golgi tendon organs [7]. The vibration-induced stretch reflex, which proceeds by way of mono- and poly-synaptic pathways, is termed the 'tonic vibration reflex' [8,9]. As an acute effect of vibration, continually activated group Ia afferent neural pathways of muscle spindles together with activation of the γ-loop (known as α-γ co-activation) [10]. Third, WBVT can be a time-efficient training modality to improve muscle fitness compared with conventional exercise modalities (e.g., resistance training, aerobic exercise, and balance training) [11]. Last, WBVT may have an act on relieving musculoskeletal pain [12,13].

Taken together, it can be expected that exercise therapy comprising of WBVT would be suitable for rehabilitation programs after ACL reconstruction to improve physical function. However, because WBVT is relatively new exercise for rehabilitation, it is still controversial whether using WBV in rehabilitation program would be meaningful for physical function enhancements compared with conventional exercise therapy after ACL reconstruction. Here, to investigate the effects of WBVT-based rehabilitation program on physical function compared with conventional exercise therapy after

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ACL reconstruction, we systematically reviewed recently published reports on short-term effects of WBVT on physical function.

Methods

Literature search strategy

Electrical databases of MEDLINE (PubMed), EBSCO (CINAHL Plus with Full Text), PEDro, and Web of Science[SM] were accessed online in December 2014 and searched using the following key words: ("whole body vibration" OR "vibration exercise" OR "vibration training" OR "vibration therapy") AND (anterior cruciate ligament [MeSH]).References lists of potentially useful articles were also scanned for additional articles.If the study title was related to WBVT, the article was selected as the first selection round. In the second selection round, we read the full articles.

Selection criteria

Eligibility criteria: The eligibility criteria for this review were: (a) the participants were individuals experienced ACL reconstruction, (b) a randomized controlled trial (RCT) that had at leastone exercise group with WBV group, (c) intervention was comprised of several exercise sessions with at least 4-week [14], and (d) any outcome measurements related to physical function.

Exclusion criteria: The exclusion criteria for this meta-analysis were: (a) locally applied vibration, (b) bed-rest studies, (c) clinical controlled trials, (d) case-control studies, (e) proceedings, (f) animal studies, and (g) when double (or triple) publications of single trial were identified.

Assessment of methodological quality

Methodological quality was assessed based on the guidelines for systematic reviews established by the Methodological Guidelines Cochrane Review [15]. Briefly, risk of bias was evaluated based on responses to seven questions inquiring about the random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other bias. In 'other bias', we mainly assessed the risk of bias, regarding compliance of exercise intervention, co-intervention, and baseline characteristics of each study group. These seven criteria were scored with 'yes', 'no', or 'unsure' based on the criteria indicated by the Cochrane Handbook for Systematic Reviews of Interventions [15].

In addition, we also evaluated the quality of each study based on the recommendation of the International Society of Musculoskeletal and Neuronal Interactions (ISMNI) for reporting WBV intervention studies, consisting of 13 factors [16]. Briefly, we evaluated whether each article adequately described the WBV-related factors based on responses to 13 questions inquiring about the WBV parameters (e.g. frequency, peak-to-peak displacement, and acceleration) and participants' position (e.g. holding bar, exercise position, and foot wear condition). Whether the article adequately described each of the above was scored with 'yes', 'no', or 'unsure'. 'Vibration displacement' was scored as 'unsure' if it was unclear whether the described displacement was peak-to-peak, and if the landmark of foot position was unclarified in case of side-alternating WBV. If we knew bar holding and foot-wear condition by figures, we scored these with 'yes'.

Data extraction

Participant and disease-specific characteristics (age, body weight, sex, and athletic performance level, ACL reconstruction method, and the severity of injury), WBV parameters (frequency, peak-to-peak displacement, and if applicable, accelerations), exercise program, and outcomes were extracted.

Data synthesis

Standardized mean difference (group contrasts) was calculated using the Review Manager version 5.3.5 (Copenhagen, Nordic Cochrane Center, The Cochrane Collaboration, 2014). Intervention effects were calculated as 'post-trial mean minus pre-trial mean' for each intervention group. The standard deviation of the difference scores from the standard deviation of each intervention group was calculated using the following equation:

$$SD_{pooled} = \sqrt{\frac{\left(N_{post}-1\right)SD^2{}_{post} + \left(N_{pre}-1\right)SD^2{}_{pre}}{N_{post}+N_{pre}-2}}$$

Where N represents the number of participants. We then calculated standardized mean differences (SMD = the Hedges' correction *g*). In addition, to clarify the effects of WBVT on postural stability, position sense, and knee stability in comparison with conventional exercise therapy (CON) group, meta-analysis was performed.

Test for heterogeneity

Heterogeneity among included studies was assessed using the Cochrane Q statistic. *P* values were obtained by comparing the Q statistic with a χ^2 distribution and κ - 1 degrees of freedom, where κ represents the number of studies included. Because heterogeneity is, to a certain degree, inevitable in meta-analysis, particularly for exercise trials, we reported the I^2 statistic using the following equation:

$$I^2 = \frac{(Q-df)}{Q} \times 100\%$$

Where Q and df are Cochran's heterogeneity statistic and the degrees of freedom, respectively. I^2 = 0%-40% indicates the absence heterogeneity, and I^2 = 30%-60%, I^2 = 50%-90%, and I^2 = 75%-100% indicate the presence of moderate, large and extremely large heterogeneity, respectively[15]. In this meta-analysis, I^2 of > 50% was used as the indication of significant heterogeneity. If significant heterogeneity was observed, a random effect meta-analysis model was applied.

Results

Study selection

As the first process, 21 potentially relevant references were identified. After reading these articles, 18 articles were excluded in this review as following reasons: review articles (n = 7); animal study (n = 1); case study (n = 1); cross-sectional studies (n = 3); not related articles (n = 4); and not individuals experienced ACL reconstruction (n = 2). Three articles were RCTs which satisfied the eligible criteria, and all were included in this review (Figure 1).

Methodological characteristics

The methodological quality scores and support information of

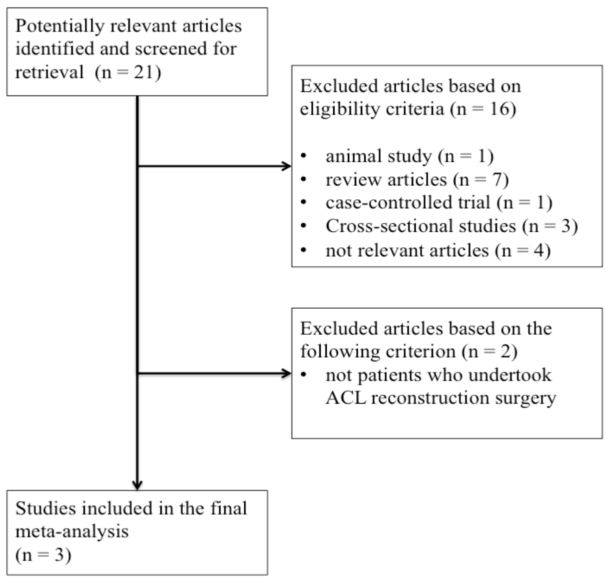

Figure 1: Flow of the meta-analysis.

Table 1: Characteristics of the studies included

Author, year	Group	WBV setting		Co-intervention	Outcomes	Drop-out rate	Adverse effects
		Device,Freq,Dis	Exercises				
Berschin, 2014	WBV (n = 20; age, 27 ± 4.2 y; FM)	Galileo, 5-30Hz, 5-9 mm	1st-5th wk:body weight exercises (1.5-2 min × 5 sets/exercise) 6th-10th wk:squat exercises(2 min × 5-7 sets/exercise) up to +30% body weight 3.8 d/wk × 10 wk,40 ± 2.3 min/session	Physical therapy 5 d/wk × 10 wk	ISOM, ISOK,postural stability test,knee laxity,LSS	0/20	Pain or swelling after exercise (60% of participants)
	CON (n = 20; age, 28 ± 6.8 y; FM)	NA		Resistance exercise and balance training3-4 d/wk× 10 wk,85 ± 4.4 min/session		0/20	Pain or swelling after exercise (70% of participants)
Fu, 2013	WBV (n = 19; age, 25.2 ± 7.3 y; FM)	Fitvibe, 35-50 Hz, 4 mm	11 body weight exercises (30-45 s/set × 1-3 sets/exercise) 2d/wk × 8 wk	WBVT and CON 2 d/wk× 1 d/wk	Position sense,knee laxity,postural stability,ISOK, range of motion,single-leg hop test,triple-hop test, shuttle run,carioca test	5/24	No
	CON (n = 20; age, 23.3 ± 5.2 y; FM)	NA				4/24	
Moezy, 2008	WBV (n = 10; age, 24.5 ± 3.4 y; M)	Power Plate, 30-50Hz, 2.5-5.0 mm	9 exercises(30-60 s/set × 1-3 sets/exercise) 3 d/wk × 4 wk	NA	Position sense,postural stability	2/12	No
	CON (n = 10; age, 22.7 ± 3.8 y; M)	NA		Resistance exercise (3sets/exercise × 8-10 exercises, 10 RM), flexibility, proprioception training		1/11	

Abbreviations: CON, conventional rehabilitation program; Dis, displacement; F, female; FM, female and male; Freq, frequency; ISOK, isokinetic muscle strength; ISOM, isometric contraction; LSS, Lysholm scoring scale; NA, not applicable; NR, not reported; RM, repetition maximum; WBV, whole-body vibration.

Devices: Fitvibe Excel Pro (model 332015; GymnaUniphy NV, Bilzen, Belgium); Galileo 2000 WBV machine (Novotec Medical GmbH,Pforzheim, Germany); Power Plate (Power Plate International, Northbrook, IL, USA).

included trials are shown in Appendix. The overall mean score was 2.0 ± 0.8(range: 1 to 3) of 7 points. The quality scores of each study followed by the ISMNI recommendation and support information are shown in Appendix. The overall mean score were 7.3 ± 1.2 (range: 6 to 9) of 13 points.

Study characteristics

Of these studies, two studies adequately described the randomization methods [17,18] while another study did not state the randomization procedure at all [19]. Table 1 shows the study design and WBV parameters in these included studies, respectively.

Subject characteristics

A total of 99 participants were included in the analysis. The mean age in each study ranged from 22.7 to 28.0 years (Table 1). The physical performance level of the participants in each study was competitive athletes of national or international level [18], non-competitive athletes [17], and unclear [19], respectively.

ACL reconstruction methods of the included studies were as follows: bone-tendon-bone method [17,19]; a single-bundle method [18]. It was unclear the severity of injury, but all participants did not experience any previous or concomitant injuries or surgeries of the knee [17-19].

Treatment characteristics

Figure 2 shows the timing of introduction of WBVT for rehabilitation after ACL reconstruction surgery in each study. During WBVT program, a conventional rehabilitation program was simultaneously conducted in the study by Fu et al. [18], whereas only WBVT was performed in the other two studies [17,19]. Mean duration of training period and number of total training sessions in all included trials were 7.3 ± 2.5 (range: 4 to 10) weeks and 22.0 ± 11.4 (range: 12 to 38) sessions, respectively. The type of WBV device varied among included studies: synchronous type [18,19]; side-alternating [17]. For progressive overloading, both WBV settings and exercise program (i.e., exercise, the duration for exercise, and the number of the training sets) were changed during the intervention period [17-19]. All participants received physical therapy immediately after ACL reconstruction surgery, and were randomly allocated to either WBVT or CON group.

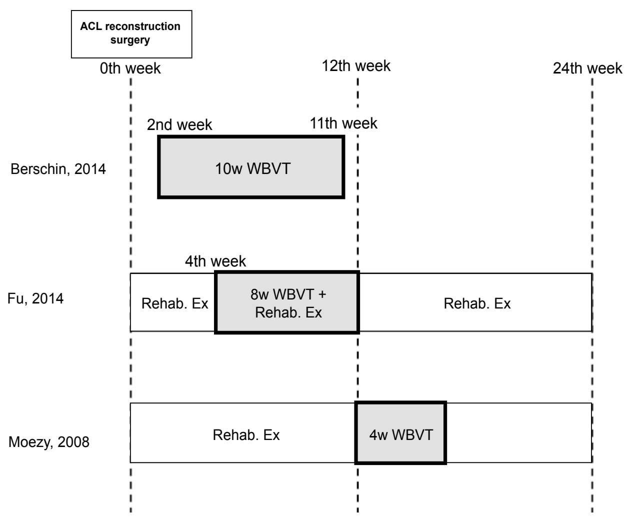

Figure 2: The timing of introduction of whole-body vibration training for rehabilitation after ACL reconstruction surgery.

ACL, anterior cruciate ligament; Ex, exercise therapy; Rehab, rehabilitation; WBVT, whole-body vibration training

Reported side effects

Two of the included studies reported that no severe side effects were observed in WBVT [18,19], whereas Berschin et al. reported that 60% of the participants experienced pain or swelling after WBVT rehabilitation program [17].

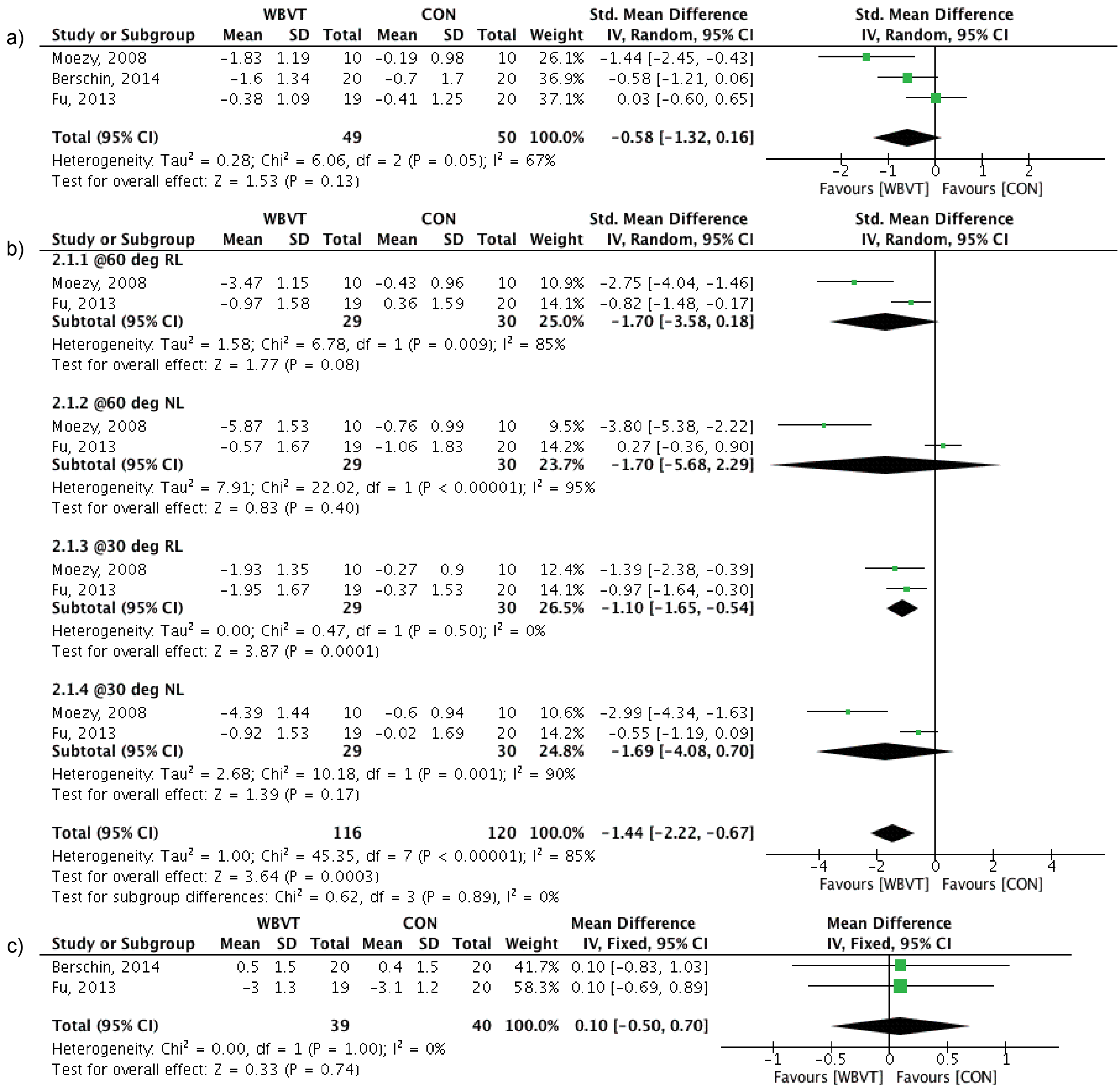

Figure 3: Meta-analysis for (a) postural stability, (b) knee position sense, and (c) knee joint laxity.

CI, confidence interval; CON, conventional rehabilitation program; WBVT, whole-body vibration training

Outcome assessments

Physical function tests were as follows: postural stability measured by Biodex Stability System (eyes-opened); knee joint reposition sense; anterior laxity of the knee using KT-1000 (MEDmetric Corp, San Diego, California); knee extension/flexion torques; other physical function tests such as single-legged and triple hop tests, shuttle run, and carioca tests.

Main effect

Standardized mean difference

Pooled data showed that no significant differences were found between WBVT and CON group in postural stability (n = 3; p > 0.05; Figure 3a) and in knee joint laxity (n = 2; p > 0.05; Figure 3c), but a significant difference was observed in knee position sense (n = 2; p < 0.01; Figure 3b).

Discussion

The methodological quality scores were poor in the included studies. In exercise therapy studies including WBVT, blinding of participants and personnel would not be realistic. Selective reporting bias was 'unclear' in almost all articles as the Cochrane review group stated, "it is likely that the majority of studies will fall into this category (unclear)" [15]. Meanwhile, all articles reported compliance and side effects, which should be important information in exercise therapy. Based on the recommendation of the Cochrane Back Review Group that drop-out rate in 1 group should be < 20% for short-term interventions (i.e., 4 to 12 weeks) [14], all included studies had no serious flaws. For the future studies, it will require configuring a study with allocation concealment, blinding assessors, and reporting the risk of co-interventions in WBV studies.

When we evaluated the quality of each study according to the ISMNI recommendations [16], included studies did not adequately report some factors related to the acceleration. First, no study measured the actual acceleration of the WBV platform. Second, because no study adequately described the information for the displacement of WBV device, it was not unsure whether the described displacement was peak-to-peak, and how a specific landmark was defined to ensure consistent targeting displacement of WBV in side-to-side alternating platform-type WBV, such as with a Galileo platform. The acceleration induced by the WBV platform affects training effects [20], it should be strictly adhered to these guidelines in future studies.

Despite the same measurement of postural stability using a Biodex device, a significant heterogeneity was observed among the included studies. The heterogeneity would be due to the timing of introduction of WBVT, exercise program and duration, and the diversity of WBV device. While Moezy et al. [19] found a significant improvement in postural stability by WBVT compared with CON program, Fu et al. [18] did not find a remarkable difference between WBVT and CON programs. In both studies, the participants performed body weight exercises on synchronous type WBV devices with similar vibration frequency and displacement (Table 1), whereas the sex of the included participants and the timing and the duration of WBVT program were apparently different. Either one or both of them might be important factor(s) to obtain higher improvement in postural stability by WBVT than by CON program. Pel et al. [21] reported that the adding weight loading to the WBV platform alters acceleration generation, and mean body weights of each study were likely to be different: Moezy et al., 74.3 kg [19] *vs.* Fu et al., 66.7 kg [18]. If body weight of participants might make difference in the enhancement of postural stability by synchronous type WBVT, participants with light body weight like women should use resistive exercise with WBV, although the effects of resistive exercise with WBV on muscle performances such as muscle strength or jump performance are equivocal in healthy young individuals [22-24]. Because higher prevalence rate of ACL injury is reported in female athletes than in male ones [1], further research is needed to investigate the influences of body weight or additional weight loading on WBVT effects after ACL reconstruction surgery.

Knee position sense was significantly improved in WBVT compared with CON. Position sense is mainly adjusted by afferent signals from proprioception, and is one of the most essential factors for sports performance [25,26]. Not only injured knee but also non-injured one would decrease position sense after ACL injury [27]. The results of this review suggest that exercise program mainly configured by bipedal exercises such as squatting might improve position sense in both knees. Although the improvement of knee position sense would contribute to prevention from re-injury, sport specific movements should be also included in rehabilitation of sports injuries [28]. Although what sports activities the participants did was not clarified in the included studies [17-19], it was promising to investigate the effects of WBVT coupled with sport specific movements on the physical performance or the prevalence of re-injury in future studies. Meanwhile, no significant difference in knee laxity between WBVT and CON programs, but one study, as previously reported [11,29], demonstrated that the time for one rehabilitation session was significantly shorter in WBVT than that of CON(40.2 ± 2.3 *vs.* 85.0 ± 4.4 min/session) [17]. Taken together, WBVT might be a time-efficient training modality compared with traditional resistance training program, and be a promising rehabilitation program after ACL reconstruction surgery.

To date, no standard WBVT regimens for rehabilitation after ACL reconstruction have been established, and therefore, the timing and duration of WBVT varied among the included studies. However, WBVT was likely to be regarded as a part of a whole rehabilitation program, which was mainly comprised of conventional physical therapy in all studies. Namely, one study configured a combination conventional rehabilitation with WBVT in the same training period for 8-week [18], whereas the other two studies did a WBVT-only training period after short-term conventional physical therapy in their rehabilitation program [17,19]. Future studies are needed to establish the rehabilitation program and the optimum time to introduce WBVT in the program, which would make the most of WBVT effects on physical function.

Previous review described that side effects of WBVT, particularly transient itching and erythema, muscle soreness, headache, forefoot pain, groin pain, fear, and knee pain were reported, and stated that these side effects were observed within the first 3-10 WBVT sessions [30]. Although more than half of the participants experienced pain or swelling after WBVT rehabilitation program in a study by Berschin et al. [17], these symptoms might not be due to WBVT *per se* because the participants of the CON group also experienced the same symptoms. The combination of ACL reconstruction method, the timing of exercise intervention, and the exercise intensity might be related to these symptoms. Further research is needed to report the side effects of exercise therapy, particularly within the first couple of WBVT sessions.

Several limitations to the present study are to be mentioned. First, it remains unclear whether WBVT can speed up the time to return to sports activities. Moreover, it is still premature for judging whether WBVT can play a role in the prevention from re-injury after rehabilitation because the included studies in this review were too much short to prevent patients from re-injury [31,32].Therefore, future research is needed to accumulate supporting information on the effects of rehabilitation program using WBVT on the preventive effects from re-injuries. Second, the present study did not conduct thoroughly meta-analysis and perform testing for funnel plot asymmetry, as the power of test is too low to distinguish chance from real asymmetry if less than 10 studies are included [15]. Therefore, the risk of publication bias could not be excluded. Third, the present study did not suggest the optimal vibration parameters or exercise prescription due to the lack of consistency in methodologies. Last, because this review excluded unpublished results (i.e., grey literature), the effects of WBVT on physical functions may possibly be overestimated [33].

In conclusion, this review suggests that WBVT might lead to improve some of the physical function tests, but its effects did not prove to be more effective compared to conventional rehabilitation program. Future studies with longer term WBVT with better quality are strongly needed.

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