Physiotherapy 102 (2016) 145–151

Systematic review

Effect of whole body vibration training on quadriceps muscle strength in individuals with knee osteoarthritis: a systematic review and meta-analysis

Shahnawaz Anwer [a,c,*], Ahmad Alghadir [a], Hamayun Zafar [b,d], Einas Al-Eisa [a]

[a] *Rehabilitation Research Chair, Department of Rehabilitation Sciences, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia*
[b] *Department of Rehabilitation Sciences, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia*
[c] *Dr. D. Y. Patil College of Physiotherapy, Dr. D. Y. Patil Vidyapeeth, Pune, India*
[d] *Department of Odontology, Clinical Oral Physiology, Umea University, Umea, Sweden*

Abstract

Background Several studies have reported the effects of whole body vibration (WBV) training on muscle strength. This systematic review investigates the current evidence regarding the effects of WBV training on quadriceps muscle strength in individuals with knee osteoarthritis (OA).
Data sources We searched PubMed, CINAHL, Embase, Scopus, PEDro, and Science citation index for research articles published prior to March 2015 using the keywords whole body vibration, vibration training, strength and vibratory exercise in combination with the Medical Subject Heading 'Osteoarthritis knee'.
Study selection This meta-analysis was limited to randomized controlled trials published in the English language.
Data extraction The quality of the selected studies was assessed by two independent evaluators using the PEDro scale and criteria given by the International Society of Musculoskeletal and Neuronal Interactions (ISMNI) for reporting WBV intervention studies. The risk of bias was assessed using the Cochrane collaboration's tool for domain-based evaluation. Isokinetic quadriceps muscle strength was calculated for each intervention.
Results Eighteen studies were identified in the search. Of these, four studies met the inclusion criteria. Three of these four studies reached high methodological quality on the PEDro scale. Out of the four studies, only one study found significantly greater quadriceps muscle strength gains following WBV compared to the control group.
Conclusions In three of the four studies that compared a control group performing the same exercise as the WBV groups, no additional effect of WBV on quadriceps muscle strength in individuals with knee OA was indicated.

Keywords: Osteoarthritis; Whole body vibration; Knee; Pain; Strength

Introduction

Knee osteoarthritis (OA) is the most common form of degenerative joint disease affecting both males and females [1,2]. The symptoms of knee OA include pain, joint stiffness and reduced quadriceps strength, causing physical disability [3]. Strength of the quadriceps muscles is a vital intrinsic factor for controlling knee joint function. The role of lower extremity strength in knee joint shock attenuation during weight bearing activities has been established. Increased or uncontrolled loading on the joint can increase the risk of development or progression of the disease; therefore, the

* Correspondence: Rehabilitation Research Chair, CAMS, King Saud University, Riyadh, Saudi Arabia. Tel.: +966 595668288.
E-mail address: anwer_shahnawazphysio@rediffmail.com (S. Anwer).

http://dx.doi.org/10.1016/j.physio.2015.10.004

strength of the quadriceps muscle needs to be considered in the study of knee OA [4]. Recently, Øiestad *et al.* [5] published a systematic review and meta-analysis to investigate the association between knee extensor muscle weakness and the risk of developing knee OA. They reported that knee extensor muscle weakness was associated with a higher risk of developing knee OA in both males and females. Another study reported an increased risk of developing knee OA in individuals with weak knee extensor muscles, especially in women [6].

Recently, the use of whole body vibration (WBV) for improving muscle strength in individuals with knee OA has been recommended as an efficient and alternative method to resistance training [7–12]. Trans *et al.* has reported increased quadriceps muscle strength following WBV exercise on a stable platform compared to a control group [8]. Another study reported significant improvement in quadriceps muscle strength following WBV exercise in women with knee pain [9]. In addition, Roelants *et al.* [12] reported improvement in quadriceps muscle strength following WBV exercise in older women. However, Park *et al.* reported that gains in quadriceps muscle strength following WBV exercises were similar compared to those of a control group [10]. WBV reduces rehabilitation time compared with other traditional resistance training programs [13].

WBV training is an exercise program performed with the body on a vibration platform [14]. These vibrations can stimulate the primary endings of the muscle spindles, and thereby activate α-motor neurons which cause muscle contractions, similar to the tonic vibration reflex [8]. WBV training can be given via two types of machine: rotational vibration (RV) and the vertical vibration (VV) machines [15]. RV machines can vibrate in two dimensions (right and left), whereas VV machines can vibrate in all three spatial dimensions. The study suggests that it is easier to maintain the correct training posture on a VV machine compared to on a RV machine [15].

Recently, Wang *et al.* published a systematic review and meta-analysis to investigate the effects of WBV on pain, stiffness and physical function in individuals with knee OA [16]. They reported that the WBV training program significantly improves physical function, but that there is no evidence that WBV can reduce pain and stiffness in individuals with knee OA. In another systematic review, Osawa *et al.* [17] investigated the effects of WBV on muscle strength and power in young and older individuals. They concluded that the addition of WBV to an exercise program enhances quadriceps muscle strength and counter movement jump performance compared to the same exercises without WBV. In addition, Zafar *et al.* [18] reported reductions in pain and improvements in function following WBV training in individuals with knee OA. More recently, Wang *et al.* [19] reported improvements in symptoms, physical function, and gait parameters following WBV training in individuals with medial compartment knee OA. However, Li *et al.* [20] reported only limited evidence to support the effectiveness of WBV in the treatment of knee OA.

To date, no systematic reviews or meta-analyses have been published regarding the effect of whole body vibration therapy on quadriceps muscle strength in individuals with knee OA. Therefore, the objective of this review was to investigate evidence regarding the effect of WBV training on quadriceps muscle strength in individuals with knee OA.

Methods

Data sources

The search was conducted in PubMed, Embase, Scopus, PEDro and the Science Citation Index, using the keywords whole body vibration, vibration therapy, strength, and vibratory exercise with 'Osteoarthritis knee', and the Medical Subject Heading 'osteoarthritis, knee' in combination with 'whole body vibration' or 'vibration'. The bibliographical survey was limited to randomized controlled trials (RCTs) published prior to March 2015. Manual searching of the references given in the identified papers was used to identify other potential papers. The studies were selected independently by two evaluators (SA and HZ), based on titles and abstracts.

Inclusion and exclusion criteria

Trials were required to compare exercise with and without WBV, or exercise with WBV and control. Studies that did not include WBV in their interventions were excluded. The outcome measure of interest was isokinetic quadriceps muscle strength in individuals with knee OA. The patients in the included studies should have had radiographic or symptomatic knee OA diagnosed by a physician.

Assessment of methodological quality

The quality of the included studies was evaluated by two independent evaluators (SA and HZ) using the PEDro scale [21]. Studies with a score equal to or more than 5 were considered high quality in the criteria given by Moseley *et al.* [22] In the present review, all studies with scores greater than or equal to 5 (5/10) were considered to be of high methodological quality. The domain-based evaluation of risk of bias was assessed using the Cochrane collaboration's tool for assessing risk of bias. Risk of bias was classified as low, unclear or high in each domain [23].

In addition, we also reviewed the quality of each study based on the recommendations of the International Society of Musculoskeletal and Neuronal Interactions (ISMNI) for reporting WBV intervention studies, consisting of 13 factors [24]. We reviewed whether each article adequately described the 13 questions inquiring about WBV parameters (e.g. frequency, amplitude, and acceleration) and the participants' position (e.g. holding on to a railing, exercise position, and foot wear condition). Based on the description of each of the above, each study was scored with 'yes', 'no', or 'unclear'. If the displacement was not described as peak-to-peak, the vibration amplitude was scored as 'unclear'. If figures showed holding on to a railing and foot-wear condition, we scored these with 'yes'.

Data analysis

Two independent evaluators (SA and HZ) reviewed the selected studies. The analysis of the included studies was conducted according to the following parameters: author/year, subjects, design, intervention, WBV parameters, outcomes, and conclusions. Both the evaluators discussed and resolve the disagreements. The kappa (κ) statistic was used to determine the agreement between the two evaluators.

The outcome measure of interest was isokinetic quadriceps muscle strength in individuals with knee OA. The mean change score (final end point minus baseline score) of isokinetic quadriceps muscle strength was calculated for each intervention. The standardized mean difference (SMD) for isokinetic quadriceps muscle strength was calculated using Hedges' (adjusted) g [$g = M1 - M2/S_{\text{pooled}}$; where, $M1$ and $M2$ are the mean change score of groups 1 and 2. S_{pooled} indicate the population standard deviation] [25].

The random effects model was conducted to determine the overall effect size of WBV. The significance of the overall effect was tested using the z statistic. Higgins I^2 statistic and the Cochran's Q statistic were used to determine statistical heterogeneity between studies [25]. Comprehensive Meta-Analysis software was used [26].

Results

Identified studies

A total of 18 studies were assessed for eligibility. Fourteen studies were excluded because they did not fulfill the inclusion criteria (Supplementary Fig. S1) [11,27–39]. The final selection of four studies [7–10] in the quality assessment phase was made by consensus.

Supplementary Fig. S1 related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.physio.2015.10.004.

Characteristics of study populations

The participant characteristics are given in Table 1. The sample sizes ranged from 35 to 47, with the mean ages varying from 52.8 to 62.5 years. All four studies included only female participants in their samples [7–10]. Most of the studies used clinical and radiographic criteria of ACR to diagnose knee OA [8,10]. One study used the Kellgren and Lawrence scale to assess severity of knee OA [9].

Training protocol

The training protocols are summarized in Table 1. All four studies [7–10] used vertical vibration. The frequency of treatment sessions varied between 2 and 3 sessions per week. The duration of treatment ranged from 8 to 12 weeks. The frequency and amplitude of the vibration signals used varied from 12 to 40 Hz, and 2 to 5 mm, respectively. One study did not specify the amplitude used [8]. The number of vibration bouts delivered per session varied from 1 to 9 for a period that lasted from 20 seconds to 10 minutes for each. The control group performed traditional quadriceps strength training program without WBV.

Effect of WBV on muscle strength

Meta-analysis of the four trials showed that most studies displayed insignificant effect size point estimate to favor WBV compared to control ($P > 0.05$), with an overall small effect size point estimate of 0.39 (95% CI, −0.130 to 0.904) based on a random-effects model (Fig. 1). A non-significant heterogeneity was found between these studies (I^2 56%, $P > 0.05$).

Quality assessment of studies

The four included studies reached an average PEDro score of **5.25/10**, as shown in Supplementary Table S1. These scores represent various sources of bias that may affect the results. The most common among them are lack of blinding (patient, therapist, or assessor) [7–10], lack of follow-up [7–10], and lack of concealed allocation [9,10]. The most adhered to items on the Pedro scale were random allocation, baseline comparability, measurements of variability, and between group comparison, which were evident in almost all of the trials. The majority of studies seem to suggest that WBV with exercise has a favorable impact on quadriceps muscle strength, but that this is not significantly increased when compared to other active interventions or controls.

Supplementary Table S1 related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.physio.2015.10.004.

An excellent agreement ($\kappa = 0.89$) between evaluators was noted in assessing risk of bias across studies. Supplementary Table S2 details the risk of bias assessment of the included studies. The risk of bias was high in two studies [9,10], and unclear in the other two [7,8].

Supplementary Table S2 related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.physio.2015.10.004.

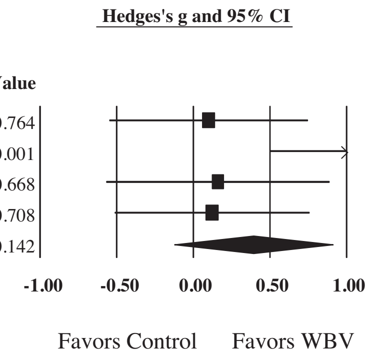
The quality score of each study followed by the ISMNI recommendation is shown in Supplementary Table S3. The overall mean score were 7 ± 1.4 (range: 6–9) of 13 points. All included studies have given the brand name and type of the vibration device used. None of the included studies clearly

Table 1
Overview of selected whole-body vibration studies in knee OA.

Study	Subjects	Mean age, years (male/female, %)	Group	WBV parameters	Frequency/ duration	Outcomes	Conclusions
Segal *et al.* [7]	Women with risk of knee OA on the basis of body mass index ≥25 kg/m^2 or history of knee injury, or surgery	Group 1: 52.8 (0/100) Group 2: 52.8 (0/100)	1: WBV-Exercise (n = 26) 2: Control-Exercise alone (n = 18)	Frequency (Hz): 35 Amplitude (mm): 2 Acceleration (g): 3.5	2/week, 12 weeks	Isokinetic quadriceps strength	WBV exercise does not improve quadriceps strength beyond that of exercise without WBV.
Trans *et al.* [8]	Knee OA based on clinical and radiographic criteria of ACR	Group 1: 61.5 (0/100) Group 2: 58.7 (0/100) Group 3: 61.1 (0/100)	1: WBV-exercise on stable platform (n = 17) 2: Control (n = 18)	Frequency (Hz): 25, 30 Amplitude (mm): ? Acceleration (g): ? Time/repetition: 30 seconds/6 to 70 seconds/9	2/week, 8 weeks	Isokinetic quadriceps muscle strength	WBV-exercise on stable platform group shows significant improvement in isokinetic peak torque of knee extension and flexion and isometric knee extension strength as compared to control group.
Tsuji *et al.* [9]	Postmenopausal women with knee pain in the age group of 50 to 75 years. Knee OA based on KL scale (0 to 4)	Group 1: 62.1 (0/100) Group 2: 60.9 (0/100)	1: Accelerated training-WBV (n = 32) 2: Control (n = 15)	Frequency (Hz): 30, 40 Amplitude (mm): 2.5 Acceleration (g): ?	3/week, 8 weeks	Isokinetic quadriceps muscle strength	No significant differences between groups were observed on muscle strength.
Park *et al.* [10]	Knee OA based on clinical and radiographic criteria of ACR	Group 1: 62.5 (0/100) Group 2: 60 (0/100)	1: WBV and home exercise (n = 17) 2: Control-home exercise (n = 19)	Frequency (Hz): 12, 14 Amplitude (mm): 2.5 to 5 Acceleration (g): ?	3/week, 8 weeks	Isokinetic quadriceps muscle strength	No significant differences between groups were observed on muscle strength.

ACR, American College of Rheumatology; RCT, randomized controlled trial; ?, not reported; WBV, whole-body vibration; OA, osteoarthritis.

Study name	Hedges's g	Lower limit	Upper limit	Z-Value	p-Value
Segal NA et al. 2013	0.100	-0.553	0.752	0.300	0.764
Trans T et al. 2009	1.213	0.496	1.930	3.316	0.001
Tsuji T et al. 2014	0.161	-0.573	0.894	0.429	0.668
Park YG et al. 2013	0.122	-0.518	0.763	0.375	0.708
	0.387	-0.130	0.904	1.467	0.142



Heterogeneity: Q- value, 6.869 (p=0.076); I-squared, 56.32%

Fig. 1. Effect of whole body vibration training on quadriceps muscle strength.

described that the given amplitude was peak-to-peak. Only one study provided information regarding acceleration [5].

Supplementary Table S3 related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.physio.2015.10.004.

Discussion

The present review is the first systematic review of the literature and meta-analysis investigating the effect of WBV on quadriceps muscle strength in individuals with knee OA. The present review evaluated four RCTs including a total of 162 participants to examine evidence regarding the effect of WBV on quadriceps muscle strength in individuals with knee OA. Among the four studies evaluated using the PEDro scale [19], three were considered of high methodological quality. Our evaluation showed that more than half of the studies performed adequate random sequence generation, whereas blinding of outcome assessment was unclear (Supplementary Table S2). Schulz and Grimes [40] reported the importance of blinding of outcome assessors to reduce differential assessment of outcomes, whereby if outcome assessors know the treatment allocation they could register better scores for one group.

As per the guidelines given by the ISMNI recommendations [24], information related to acceleration was not documented in most of the included studies. Only one study reported the acceleration of the WBV and described the method used to ensure consistent targeting amplitude of WBV [7]. Therefore, the optimal vibration protocol (amplitude, frequency, and duration of the vibration signal) cannot be provided. In addition, the acceleration parameter is one of the most salient factors in WBV studies; therefore, future studies should strictly adhere to these guidelines [41].

In the present review, exercises with WBV show similar improvements in muscle strength compared to the control protocol. This is in agreement with the results of Rapp *et al.* who reported a similar effect of WBV exercise compared to traditional strength training for strength gain in individuals with knee OA [11]. Similarly, Roelants *et al.* reported similar effects of WBV training on muscle strength as compared to conventional resistance training [12].

In contrast, Bogaerts *et al.* reported greater effects of WBV training on muscle strength compared to control group in community-dwelling men and women over the age of 60 years [32]. Another study reported greater increases in isometric knee extensor strength following WBV exercise compared with control subjects [42]. The differences in the results with the current studies may be due to the different treatment protocol, measurements, and participants' characteristics. In the Bogaerts *et al.* [32] study, community-dwelling individuals with no history of knee OA participated in WBV training for 12 months. In the Osawa *et al.* [42] study, the participants were healthy males and females. Both of these studies measured isometric knee extension strength. Recently, Osawa *et al.* [17] reported additional gains in muscle strength following WBV training along with an exercise program in young and older individuals. It is hypothesized that when vibration is applied to the muscle belly or tendon, the Ia afferent neurons of the muscle spindles are activated more than the II afferent neurons and Golgi tendon organs [43]. Therefore, vibrations could inhibit antagonist muscle activations through Ia inhibitory neurons, thereby resulting in a higher force production.

In a previous study, Darling and Athanasiou [44] reported that mechanical stimuli play a vital role for the development of cartilaginous tissue. Furthermore, an *in vitro* study suggested that mechanical vibration stimulated the proliferation of chondrocytes [45]. If vibration training is found to be safe and provides controlled mechanical stimulus, it is reasonable to suggest that vibration may be a potential non-pharmacological treatment of OA.

Most of the included studies reported a priori sample size calculation to determine adequate power ($n = 162$ in four included studies). There was variation in the duration and content of the exercise programs included in our review. Length of interventions ranged from 8 to 12 weeks, with frequency of intervention ranging from 2 to 3 sessions per week. There was considerable variation in the parameters of the WBV included in our systematic review. Variations among the four studies included: duration of intervention, type of control groups, and vibration parameters including frequency, amplitude, and acceleration.

There are several limitations in the present review. The sample size was small as only four studies were included. Only female participants were involved in the selected studies. In this review, no study assessed the isolated effect of WBV on outcome. For example, it is undetermined whether isolated WBV would yield similar or better effects than when utilized in combination with other interventions. This would be an important area of research to determine the clinical effectiveness of WBV. Moreover, different vibration platforms have different technical characteristics and may induce different therapeutic effects, such as reduction in pain, and improvements in bone density, postural control, and function. None of the selected studies attempted to compare the effects of different vibration platforms. Furthermore, none of the selected studies evaluated the long-term effects of WBV on outcome. In addition, the present study did not suggest optimal vibration parameters due to the lack of consistency in methodologies.

Conclusion

According to the present review, WBV provide no extra benefits on quadriceps muscle strength when compared to a control group performing the same exercises as the WBV groups in individuals with knee OA. In the present review, there is lack of uniformity in the vibration protocol, training dose and reported results. Hence, more studies are required for conclusive evidence of the effect on quadriceps muscle strength of WBV training in individuals with knee OA.

Acknowledgment

The project was full financially supported by King Saud University, Vice Deanship of Research Chairs, Rehabilitation Research Chair.

Funding: Rehabilitation Research Chair, King Saud University.

Conflict of interest: None declared.

References

[1] Michael JW, Schluter-Brust KU, Eysel P. The epidemiology, etiology, diagnosis, and treatment of osteoarthritis of the knee. Dtsch Arztebl Int 2010;107(9):152–62.

[2] Cho HJ, Chang CB, Kim KW, Park JH, Yoo JH, Koh IJ, *et al.* Gender and prevalence of knee osteoarthritis types in elderly Koreans. J Arthroplasty 2011;26(7):994–9.

[3] Dawson J, Linsell L, Zondervan K, Rose P, Randall T, Carr A, *et al.* Epidemiology of hip and knee pain and its impact on overall health status in older adults. Rheumatology 2004;43(4):497–504.

[4] Minor MA. Exercise in the treatment of osteoarthritis. Rheum Dis Clin N Am 1999;25(2):397–415, viii.

[5] Øiestad BE, Juhl CB, Eitzen I, Thorlund JB. Knee extensor muscle weakness is a risk factor for development of knee osteoarthritis. A systematic review and meta-analysis. Osteoarthr Cartil 2015;23(2):171–7.

[6] Segal NA, Torner JC, Felson D, Niu J, Sharma L, Lewis CE, *et al.* Effect of thigh strength on incident radiographic and symptomatic knee osteoarthritis in a longitudinal cohort. Arthritis Rheum 2009;61(9):1210–7.

[7] Segal NA, Glass NA, Shakoor N, Wallace R. Vibration platform training in women at risk for symptomatic knee osteoarthritis. PM&R 2013;5(3):201–9.

[8] Trans T, Aaboe J, Henriksen M, Christensen R, Bliddal H, Lund H. Effect of whole body vibration exercise on muscle strength and proprioception in females with knee osteoarthritis. Knee 2009;16(4): 256–61.

[9] Tsuji T, Yoon J, Aiba T, Kanamori A, Okura T, Tanaka K. Effects of whole-body vibration exercise on muscular strength and power, functional mobility and self-reported knee function in middle-aged and older Japanese women with knee pain. Knee 2014;21(December (6)):1088–95, http://dx.doi.org/10.1016/j.knee.2014.07.015 [Epub 2014 July 28].

[10] Park YG, Kwon BS, Park JW, Cha DY, Nam KY, Sim KB, *et al.* Therapeutic effect of whole body vibration on chronic knee osteoarthritis. Ann Rehabil Med 2013;37(4):505–15.

[11] Rapp W, Boeer J, Albrich C, Heitkamp HC. Auswirkung eines vibrations und kraft trainings auf die beinmuskulatur bei gonarthrosepatienten [Efficiency of vibration or strength training for knee stability in osteoarthritis of the knee]. Aktuelle Rheumatologie 2009;34(4):240–5 [in German].

[12] Roelants M, Delecluse C, Verschueren SM. Whole-body-vibration training increases knee-extension strength and speed of movement in older women. J Am Geriatr Soc 2004;52(6):901–8.

[13] Connolly LJ, Scott S, Mohr M, Ermidis G, Julian R, Bangsbo J, *et al.* Effects of small-volume soccer and vibration training on body composition, aerobic fitness, and muscular PCr kinetics for inactive women aged 20–45. J Sport Health Sci 2014;3(4):284–92.

[14] Cardinale M, Bosco C. The use of vibration as an exercise intervention. Exerc Sport Sci Rev 2003;31(1):3–7.

[15] Merriman H, Jackson K. The effects of whole-body vibration training in aging adults: a systematic review. J Geriatr Phys Ther 2009;32(3):134–45.

[16] Wang P, Yang X, Yang Y, Yang L, Zhou Y, Liu C, *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(October (10)): 939–51, http://dx.doi.org/10.1177/0269215514564895 [Epub 2014 December 18].

[17] Osawa Y, Oguma Y, Ishii N. The effects of whole-body vibration on muscle strength and power: a meta-analysis. J Musculoskelet Neuronal Interact 2013;13(3):380–90.

[18] Zafar H, Alghadir A, Anwer S, Al-Eisa E. 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.

[19] Wang P, Yang L, Li H, Lei Z, Yang X, Liu C, *et al.* Effects of whole-body vibration training with quadriceps strengthening exercise on functioning and gait parameters in patients with medial compartment knee osteoarthritis: a randomised controlled preliminary study. Physiotherapy 2015. pii:S0031-9406(15)03777-3.

[20] Li X, Wang XQ, Chen BL, Huang LY, Liu Y. Whole-body vibration exercise for knee osteoarthritis: a systematic review and meta-analysis. Evid Based Complement Alternat Med 2015;2015:758147.

[21] Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. Phys Ther 2003;83(8):713–21.

[22] Moseley AM, Herbert RD, Sherrington C, Maher CG. Evidence for physiotherapy practice: a survey of the Physiotherapy Evidence Database (PEDro). Aust J Physiother 2002;48(1):43–9.

[23] Higgins JPT, Altman DG. Assessing risk of bias in included studies. In: Higgins JPT, Green S, editors. Cochrane handbook for systematic reviews of interventions version 5.0.1. Oxford: The Cochrane Collaboration; 2008.
[24] Rauch F, Sievanen H, Boonen S, Cardinale M, Degens H, Felsenberg D, *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.
[25] Higgins J, Green S. Cochrane handbook for systematic reviews of interventions version 5.0.0. Chichester, United Kingdom: The Cochrane Collaboration; 2008.
[26] Comprehensive meta-analysis version 2.0 [Computer software]. Englewood, NJ: Biostat; 2014.
[27] Kitay GS, Koren MJ, Helfet DL, Parides MK, Markenson JA. Efficacy of combined local mechanical vibrations, continuous passive motion and thermotherapy in the management of osteoarthritis of the knee. Osteoarthr Cartil 2009;17(10):1269–74.
[28] Osugi T, Iwamoto J, Yamazaki M, Takakuwa M. 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, http://dx.doi.org/10.2147/TCRM.S57806 [eCollection 2014].
[29] Blackburn JT, Pamukoff DN, Sakr M, Vaughan AJ, Berkoff DJ. Whole body and local muscle vibration reduce artificially induced quadriceps arthrogenic inhibition. Arch Phys Med Rehabil 2014;95(11):2021–8.
[30] Mikhael M, Orr R, Amsen F, Greene D, Singh MA. Effect of standing posture during whole body vibration training on muscle morphology and function in older adults: a randomised controlled trial. BMC Geriatr 2010;10:74.
[31] Sitjà-Rabert M, Martínez-Zapata MJ, Fort-Vanmeerhaeghe A, Rey-Abella F, Romero-Rodríguez D, Bonfill X. Whole body vibration for older persons: an open randomized, multicentre, parallel, clinical trial. BMC Geriatr 2011;11:89.
[32] Bogaerts AC, Delecluse C, Claessens AL, Troosters T, Boonen S, Verschueren SM. Effects of whole body vibration training on cardiorespiratory fitness and muscle strength in older individuals (a 1-year randomised controlled trial). Age Ageing 2009;38(4):448–54.
[33] Bogaerts A, Delecluse C, Claessens AL, Coudyzer W, Boonen S, Verschueren SM. Impact of whole-body vibration training versus fitness training on muscle strength and muscle mass in older men: a 1-year randomized controlled trial. J Gerontol A: Biol Sci Med Sci 2007;62(6):630–5.
[34] Salmon JR, Roper JA, Tillman MD. Does acute whole-body vibration training improve the physical performance of people with knee osteoarthritis? J Strength Cond Res 2012;26(11):2983–9.
[35] Stein G, Knoell P, Faymonville C, Kaulhausen T, Siewe J, Otto C, *et al.* Whole body vibration compared to conventional physiotherapy in patients with gonarthrosis: a protocol for a randomized, controlled study. BMC Musculoskelet Disorders 2010;11:128.
[36] Tossige-Gomes R, Avelar NC, Simão AP, Neves CD, Brito-Melo GE, Coimbra CC, *et al.* Whole-body vibration decreases the proliferative response of TCD4(+) cells in elderly individuals with knee osteoarthritis. Braz J Med Biol Res 2012;45(12):1262–8.
[37] Yoon J, Tsuji T, Kanamori A, Tanaka K, Okura T. The effects of whole-body vibration training on knee function and physical performance of middle-aged and elderly woman with knee osteoarthritis and chronic knee pain. Jpn J Phys Fit Sports Med 2014;63(4):371–82 [in Japanese].
[38] Simão AP, Avelar NC, Tossige-Gomes R, Neves CD, Mendonça VA, Miranda AS, *et al.* Functional performance and inflammatory cytokines after squat exercises and whole-body vibration in elderly individuals with knee osteoarthritis. Arch Phys Med Rehabil 2012;93(10):1692–700.
[39] Avelar NC, Simão AP, Tossige-Gomes R, Neves CD, Rocha-Vieira E, Coimbra CC, *et al.* The effect of adding whole-body vibration to squat training on the functional performance and self-report of disease status in elderly patients with knee osteoarthritis: a randomized, controlled clinical study. J Altern Complement Med 2011;17(12):1149–55.
[40] Schulz KF, Grimes DA. Blinding in randomised trials: hiding who got what. Lancet 2002;359(9307):696–700.
[41] 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.
[42] Osawa Y, Oguma Y. Effects of resistance training with whole-body vibration on muscle fitness in untrained adults. Scand J Med Sci Sports 2011;10:328–37.
[43] Ribot-Ciscar E, Vedel JP, Roll JP. Vibration sensitivity of slowly and rapidly adapting cutaneous mechanoreceptors in the human foot and leg. Neurosci Lett 1989;104:130–5.
[44] Darling E, Athanasiou K. Articular cartilage bioreactors and bioprocesses. Tissue Eng 2003;9(1):9–26.
[45] Kaupp J, Waldman S. Mechanical vibrations increase the proliferation of articular chondrocytes in high-density culture. Proc Inst Mech Eng [H] 2008;222(5):695–703.