Meta-Analysis

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Does vibration benefit delayed-onset muscle soreness?: a meta-analysis and systematic review

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Abstract

Objective: Delayed-onset muscle soreness (DOMS) is a symptom of exercise-induced muscle injury that is commonly encountered in athletes and fitness enthusiasts. Vibration is being increasingly used to prevent or treat DOMS. We therefore carried out a meta-analysis to evaluate the effectiveness of vibration in patients with DOMS.

Method: We searched nine databases for randomized controlled trials of vibration in DOMS, from the earliest date available to 30 May 2018. Visual analogue scale (VAS) and creatine kinase (CK) levels were set as outcome measures.

Results: The review included 10 identified studies with 258 participants. The meta-analysis indicated that vibration significantly improved the VAS at 24, 48, and 72 hours after exercise, and significantly improved CK levels at 24 and 48 hours, but not at 72 hours.

Conclusion: Vibration is a beneficial and useful form of physiotherapy for alleviating DOMS. However, further studies are needed to clarify the role and mechanism of vibration in DOMS.

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Introduction

Frequent habitual exercise can reduce the risks of obesity and cardiovascular disease; however, excessive exercise or sport can also elicit temporary muscle injury, which presents as delayed-onset muscle soreness (DOMS).[1] DOMS indicates subclinical muscle damage, which serves as a precursor to ancillary complications.[2] Growing reports have shown that DOMS represents a type I muscle strain injury, resulting in muscle aches, pain, discomfort, and inflammation.[3] DOMS is characterized by allodynia in the distal portions of skeletal muscles, peaking at around 24 to 48 hours after exercise, and thus differs from normal muscle soreness, which occurs immediately after exercise.[4] DOMS usually occurs in competitive athletes or people who participate in excessive sport, and has become a major challenge in many sports.[5]

Numerous recovery modalities have been developed to offset the adverse effects of DOMS by promoting the recovery process after muscle injury, such as massage, cold water immersion, and vibration.[6,7] Vibration treatments typically consist of local mechanical vibration (LV) administered directly to the muscle or tendon, or whole-body vibration (WBV), performed by vibrating platforms or devices fixed to resistance training machines.[8] Vibration treatment is becoming more popular in the field of sports, with the aim of enhancing skeletal musculature performance and injury recovery.[9] Vibration has also been shown to increase morphological functional development of muscle fibers.[10,11] Moreover, both LV and WBV therapies have demonstrated beneficial preventive and therapeutic effects in sports rehabilitation.[12,13]

However, the efficacy of vibration for DOMS remains controversial. Two studies reported that vibration therapy was no more effective than massage or placebo in patients with DOMS,[14,15] while other studies found that vibration promoted the recovery of DOMS and relieved pain.[2,16,17] A previous review in 2012 indicated that WBV had potential beneficial effects for muscle recovery after exercise.[18] Moreover, another systematic review in 2014 also showed benefits of vibration on DOMS,[19] though this was a descriptive systematic review rather than a quantitative synthesis of the evidence. There is thus a lack of strong evidence regarding the effectiveness of vibration for the treatment of DOMS. Few randomized controlled trials (RCTs) concerning the effect of vibration on DOMS had been conducted up to 2014, though some new RCTs have since been carried out. We therefore aimed to clarify the beneficial effect of vibration in patients with DOMS by conducting a meta-analysis based on available RCT data.

Methods

Search strategy

We searched the following electronic databases: PubMed, the Cochrane Library, Embase, Web of Science, SPORTDICUS,

Physiotherapy Evidence Database, China National Knowledge Infrastructure (CNKI), Chinese Biomedical Literature Database (SinoMed), and WanFang. There were no exclusions on the basis of language. Databases were searched from the earliest date available to May 30, 2018, using the terms ("vibration") AND ("delayed onset muscle soreness") AND ("randomized controlled trial"). Equivalent Chinese terms were used to search Chinese language databases.

Inclusion criteria

The inclusion criteria were: (1) RCTs; (2) trials that contained subjects suffering from DOMS; (3) vibration as the intervention (either WBV with subjects sitting, standing, lying on a platform, or LV to regional muscles or other local regions using with wearable devices, vibrators, cushions, insoles, or footwear); (4) controls received placebo vibration or conventional physical therapy; and (5) outcome measures were visual analogue scale (VAS) or serum creatine kinase (CK) levels.

Exclusion criteria

Studies were excluded if they were: (1) quasi-experimental studies (non-RCTs, before and after, interrupted time series, crossover trials), observational studies (prospective and retrospective), case reports, reviews or systematic literature reviews and qualitative studies, opinion pieces, editorials, comments, news, and letters; (2) the mean and standard deviation could not be obtained from the articles, and no further information was obtained from correspondence with the authors; and (3) muscle soreness was reported within 12 hours of exercise.

Study selection and data extraction

Two of the authors independently screened the literature using the above predetermined inclusion criteria and extracted the following data from the trials: study design, participant characteristics, intervention and outcome data, adverse effects, and methodological quality. If the data were incomplete, we attempted to contact the authors to obtain additional details. Disagreements about study inclusion and extracted data were resolved by consensus between the two coauthors. If disagreements persisted, the coauthors consulted with a third author.

Risk of bias

Risk of bias was assessed according to the evaluation criteria provided by the Cochrane Handbook for Systematic Reviews of Interventions and by examining the random sequence generation, allocation concealment, incomplete outcome data, blinding (participants, personnel, and an outcome assessment), selective reporting, and other biases. Two review authors independently assessed the risk of bias of the included studies, and judged each domain as having bias, a high risk of bias, or an unclear risk of bias, respectively.

Subgroup analysis and sensitivity analysis

Subgroup and sensitivity analyses were performed to explore the possible reasons for statistical heterogeneity when $I^2 > 50\%$. Sensitivity analysis was performed by omitting studies one at a time. Subgroup analyses in relation to the primary outcomes were performed to compare different vibrations, and types of control interventions (i.e., vibration before or after exercise, vibration frequency, and duration of vibration). Some data, such as participants' mean age and medical history, were not obtained or were missing for some studies and no subgroup analyses of these variables were therefore performed.

Publication bias

Asymmetry and potential publication bias were investigated visually by Funnel plots and quantitatively by Egger's test for at least 10 studies.

Statistical analysis

Data analysis was carried out using Review Manager software (Revman, Version 5.3) provided by the Cochrane Collaboration, and STATA 14.0 (StataCorp LP, College Station, TX, USA). Continuous variables were analyzed by calculating the standardized mean difference (SMD) and 95% confidence interval (CI). We conducted tests of heterogeneity for each outcome using the χ^2 test and I^2 statistic. The meta-analysis was carried out using a fixed-effects model if no significant heterogeneity was observed ($P > 0.05$ and $I^2 < 50\%$), and a random-effects model if heterogeneity was detected ($P < 0.05$ and $I^2 \geq 50\%$).

Results

Literature search

The preliminary search identified 999 studies, comprising 906 studies in English, one in Arabic, and 92 in Chinese. After excluding 467 duplicated studies, the titles and abstracts of the remaining 532 studies were inspected; 500 studies were excluded based on title and abstract criteria, and the remaining 32 studies were screened by full-text review. Among these 32 studies, one was not a RCT,[20] three were crossover trials,[21–23] and two studies did not investigate the curative effect of vibration on DOMS.[24,25] Furthermore, some studies only presented the mean and standard deviation in figures, and no further information was obtained by attempted correspondence with the authors.[5,15,16,26–31] Five studies did not include information on VAS (primary outcome) or CK (secondary outcome),[2,31–34] and only one trial demonstrated the magnitudes of changes in VAS and CK.[17] One abstract was deemed to be too low quality, with confusion between the groups and a lack of units for CK levels.[35] Ten studies were finally included after consideration of the inclusion and exclusion criteria and after careful reading of the full texts. The literature screening process and results are shown in the attached flow diagram (Figure 1).

Description of included studies

Ten studies involving 258 participants were obtained for analysis, including two in Chinese[36,37] and eight in English. The studies were performed in Australia,[12] Spain,[38,39] Korea,[40,41] Iran,[42,43] New Zealand,[8] and China,[36,37] respectively. Five studies included only male subjects,[8,14,37,39,41] three studies included both male and female subjects,[40,42,43] and two studies did not report the sex of the participants.[36,38] Most of the studies used no intervention in the control group,[8,36,38,40–43] one used standard massage as a conventional physiotherapy control,[14] and two studies used static stretching as a control and a combination of static stretching and vibration as the intervention.[36,39] An additional description of the other data is indicated in Table 1. Information on the VAS and CK levels at 24, 48, and 72 hours after exercise was extracted for this analysis.

Risk of bias

Two independent reviewers assessed the risk of bias, according to allocation, blinding, incomplete outcome bias, selective reporting bias, and other bias. As shown in Figure 2a and 2b, two studies described the generation of the random sequences and allocation concealment, and were evaluated as having a low risk of bias.[14,42] The other studies mentioned 'random' assignment but did not provide any detailed description of the random sequence generation and were

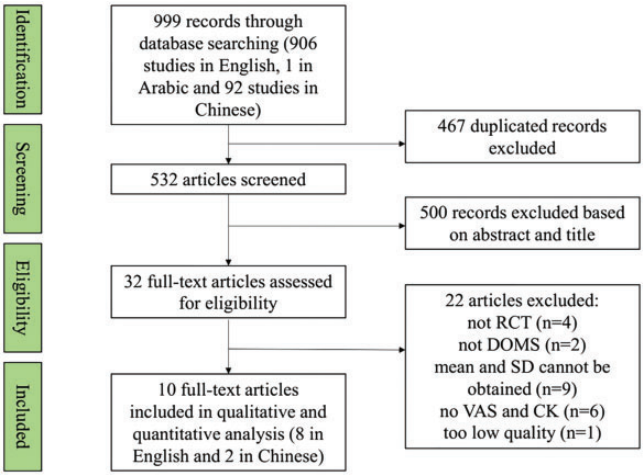

Figure 1. Flow diagram of literature search and results

therefore judged to have an unclear risk of bias. Two studies used single blinding,[14,38] while the others did not mention any blinding of participants or researchers. However, given that the participants were likely to have felt the vibration during the intervention, we considered that the importance of blinding in a physiotherapy RCT was less important than in a drug trial.[44] None of the included studies reported blinding in the outcome recorders.

Effect of vibration on VAS rating at 24 hours

Analysis of nine studies with 238 participants indicated that the VAS scores at 24 hours after exercise decreased significantly in participants who received the vibration intervention compared with the control group (SMD = −1.53, 95% CI = −2.57 to −0.48, $P = 0.004$, $I^2 = 91\%$) (Figure 3a). The VAS scores were derived from the right leg in Bakhtiary et al.[42] and from the flexion data in Aminian-Far et al.[43] VAS analysis for the right leg and extension showed SMD = −1.28, 95% CI = −2.21 to −0.35, $P = 0.007$, $I^2 = 89\%$, analysis for the left leg and flexion showed SMD = −1.50, 95% CI = −2.53 to −0.47, $P = 0.004$, $I^2 = 91\%$, and VAS analysis for the left leg and extension showed SMD = −1.26, 95% CI = −2.18 to −0.34, $P = 0.008$, $I^2 = 89\%$.

Effect of vibration on VAS rating at 48 hours

Analysis of eight studies with 188 participants demonstrated that the VAS scores at 48 hours after exercise also decreased significantly after vibration intervention, compared with the control group (SMD = −2.04, 95% CI = −3.40 to −0.69, $P = 0.003$, $I^2 = 92\%$). The VAS scores were derived from data in flexion in Aminian-Far et al.[43]) (Figure 3b). The results for VAS in extension were SMD = −2.03, 95% CI = −3.39 to −0.68, $P = 0.003$, $I^2 = 92\%$.

Effect of vibration on VAS rating at 72 hours

Analysis of six studies with 150 participants showed significant improvement in VAS scores at 72 hours after exercise following vibration intervention compared with the control group (SMD = −1.60, 95%

Table 1. Descriptions of 10 included studies

Author	Year	Study design	Participants	Method inducing DOMS	Groups	Vibration intervention	Outcomes	Data time point
Shen[37]	2017	RCT	30 Male students from Beijing Sports University	Maximum force used for frog-leaping exercise (15 or 8 per group). Rest time 3 minutes	1. Control group (n=6); 2. No-intervention group (n=6); 3. Vibration group (n=6); 4. Static stretch group (n=6); 5. Complex training group (n=6)	WBV using a Power Plate Pro5; vibration applied for 3 consecutive days from first day after exercise for 60 s, 35 Hz, amplitude 2 mm, repeated twice for each training	VAS	Before and 12, 24, 48, 72, and 96 hours after exercise
Song and Liu[36]	2017	RCT	27 Soccer students	Downhill running for 30 minutes	1. Control group (n=9); 2. Vibration combined with static stretch group (n=9); 3. Static stretch group (n=9)	WBV using a Power Plate administered after exercise for 60 s, 30 Hz, amplitude 1.5 mm, repeated 3 times	VAS, CK, LDH, ROM	Before and 24, 48, and 72 hours after exercise
Bakhtiary et al.[42]	2007	RCT	50 Non-athletic volunteers (25 females, 25 males)	Downhill walking on a declined treadmill at 4 km/h for 30 minutes	1. Vibration group (n=25); 2. Non-vibration group (n=25)	LV applied to mid-line of left and right quadriceps, hamstring, and calf muscles using a vibrator apparatus (Model VR-7N, ITO) after downhill treadmill walking for 1 minute at 50 Hz	Isometric maximum voluntary contraction, PPT, VAS, CK	Before and 24 hours after exercise

(continued)

Table 1. Continued

Author	Year	Study design	Participants	Method inducing DOMS	Groups	Vibration intervention	Outcomes	Data time point
Fuller et al.[14]	2015	RCT	50 Untrained men	100 Maximal eccentric muscle actions of knee extensor muscles of the right leg	1. Stretching and sports massage group (n=25); 2. Vibration group (n=25)	LV applied to under the right thigh using a cycloidal vibration cushion, twice daily after exercise for 20 minutes with 73 Hz, 0.5 mm	PIT, VAS, CK, C-reactive protein, myoglobin	Before, and immediately, 24, 48, 72, and 168 hours after exercise
Timon et al.[38]	2016	RCT	20 University students	Eccentric strength training consisting of 5-minute warm up (30% 1 RM) and 4 sets of 5 repetitions at 120% 1RM, with 4 minutes rest between sets, with quadriceps leg extension	1. Control group (n=10); 2. Vibration group (n=10)	WBV using a vibratory platform (Galileo Fitness) administered after exercise for 60 s, 12 Hz, amplitude 4 mm, repeated 3 times with 30-s intervals	CK, blood urea nitrogen, VAS, PIT	Before and immediately and 24 and 48 hours after exercise
Kim et al.[40]	2011	RCT	21 University students (men and women)	Centrifugal contraction exercise conducted on biceps with 70% maximum isometric muscular strength	1. Control group (n=7); 2. Vibration group (n=7); 3. Ultrasound group (n=7)	WBV using a sonic vibrator at 26 Hz for 11 minutes	VAS, PPT	Before and 24, 48, and 72 hours after exercise
Cochrane[8]	2017	RCT	26 Arms (Male)	10 Sets of 6 maximal voluntary eccentric repetitions performed on an isokinetic dynamometer	1. Control group (n=13); 2. Vibration group (n=13)	LV applied to the biceps brachii and treatment arm using a vibratory device (MyoVolt, Christchurch) after exercise for 15 minutes at 120 Hz	Electromyography, VAS, PPT, CK, ROM, normalized isometric strength, concentric strength	Before and immediately and 24, 48, and 72 hours after exercise

(continued)

Table 1. Continued

Author	Year	Study design	Participants	Method inducing DOMS	Groups	Vibration intervention	Outcomes	Data time point
Kim et al.[41]	2017	RCT	30 Healthy male adults	Weight-bearing arm using weight equivalent to 60% of one repetition maximum slowly lowered at the same pace and lift with assistance	1. Control group (n=10); 2. Vibration before exercise group (n=10); 3. Vibration after exercise group (n=10)	LV applied to the middle of biceps muscle using an AT-1000 system during a relaxed state before or after exercise for 5 minutes, 60 Hz	PPT, CK, LDH	Before and 24, 48, and 72 hours after exercise
Aminian-Far et al.[43]	2011	RCT	32 Untrained volunteers (22 women and 10 men)	Exercise performed on the dominant-limb knee extensors against the lever arm of the isokinetic dynamometer	1. Vibration group (n=15); 2. Control group (n=17)	WBV applied using a Power Plate Pro 5 before eccentric exercise at 35 Hz, 5 mm for 60 s	Tight circumference, PPT, VAS, maximal isometric torque, PIT, CK	Before and 1, 2, 3, 4, 7, and 14 days after exercise
Rhea et al.[39]	2009	RCT	16 Adult men	Exercise including resistance training and repeated sprint exercise	1. Static stretch group (n=8); 2. Static stretch with WBV group (n=8)	WBV applied using an iTonic platform immediately after exercise and again later the same day. Vibration performed after exercise for 30 s, 50 Hz, 2 mm amplitude with the gastrocnemius, hamstring and quadriceps muscles on the platform	VAS	Before and 12, 24, 48, and 72 hours after exercise

RCT: randomized controlled trial; VAS: visual analogue scale; WBV: whole-body vibration; LV: local vibration; CK: creatine kinase, PIT: peak isometric torque; LDH: lactate dehydrogenase; ROM: range of motion; PPT: pressure pain threshold; RM: repetition maximum.

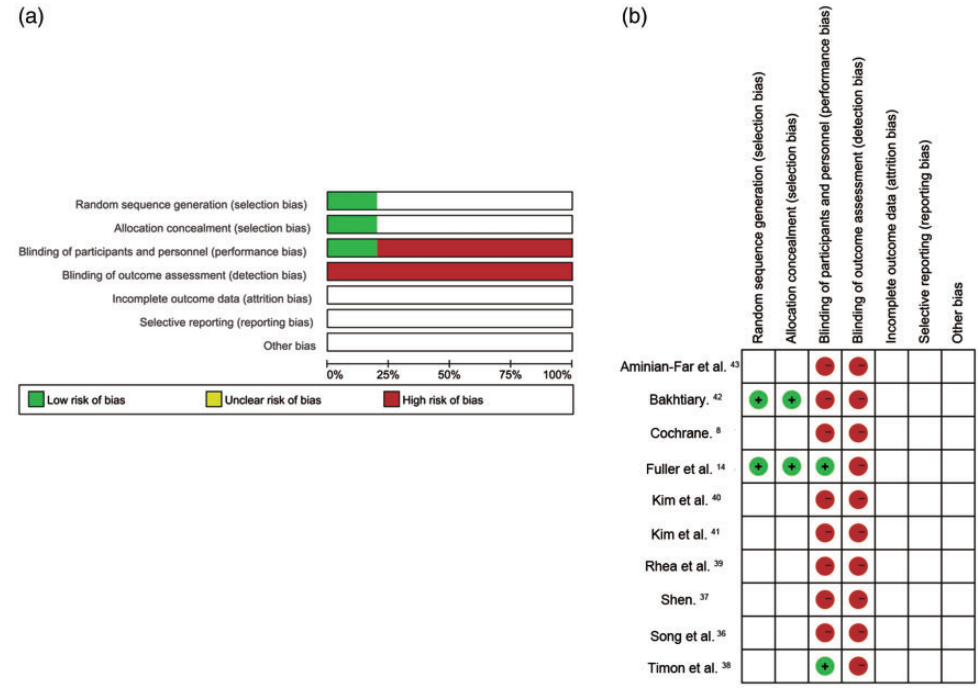

Figure 2. Risk-of-bias graph (a) and summary (b)

CI = −2.99 to −0.21, $P = 0.02$, $I^2 = 88\%$) (Figure 3c).

Effect of vibration on CK levels at 24 hours

Analysis of five studies with 146 participants indicated that CK levels decreased significantly at 24 hours following vibration intervention compared with the control groups (SMD = −1.46, 95% CI = −2.66 to −0.27, $P = 0.02$, $I^2 = 89\%$) (Figure 4a). The CK data in Kim et al.[41] were derived from pre-exercise data, and when the post-exercise data were adopted, the results were SMD = −1.29, 95% CI = −2.45 to −0.14, $P = 0.03$, $I^2 = 88\%$.

Effect of vibration on CK levels at 48 hours

Analysis of four studies with 96 participants showed that CK levels decreased significantly 48 hours after vibration intervention, compared with the control group (SMD = −6.20, 95% CI = −10.90 to −1.44, $P = 0.01$, $I^2 = 96\%$) (Figure 4b). The CK data in Kim et al.[41] were derived from pre-exercise data, and when the post-exercise data were adopted, the results were SMD = −6.10, 95% CI = −10.89 to −1.30, $P = 0.01$, $I^2 = 96\%$.

Effect of vibration on CK levels at 72 hours

Analysis of three studies with 76 participants indicated that there was no significant difference in CK levels at 72 hours after vibration intervention compared with the control groups (Figure 4c). The CK data in Kim et al.[41] were derived from pre-exercise data, but the result remained non-significant when the post-exercise data were adopted.

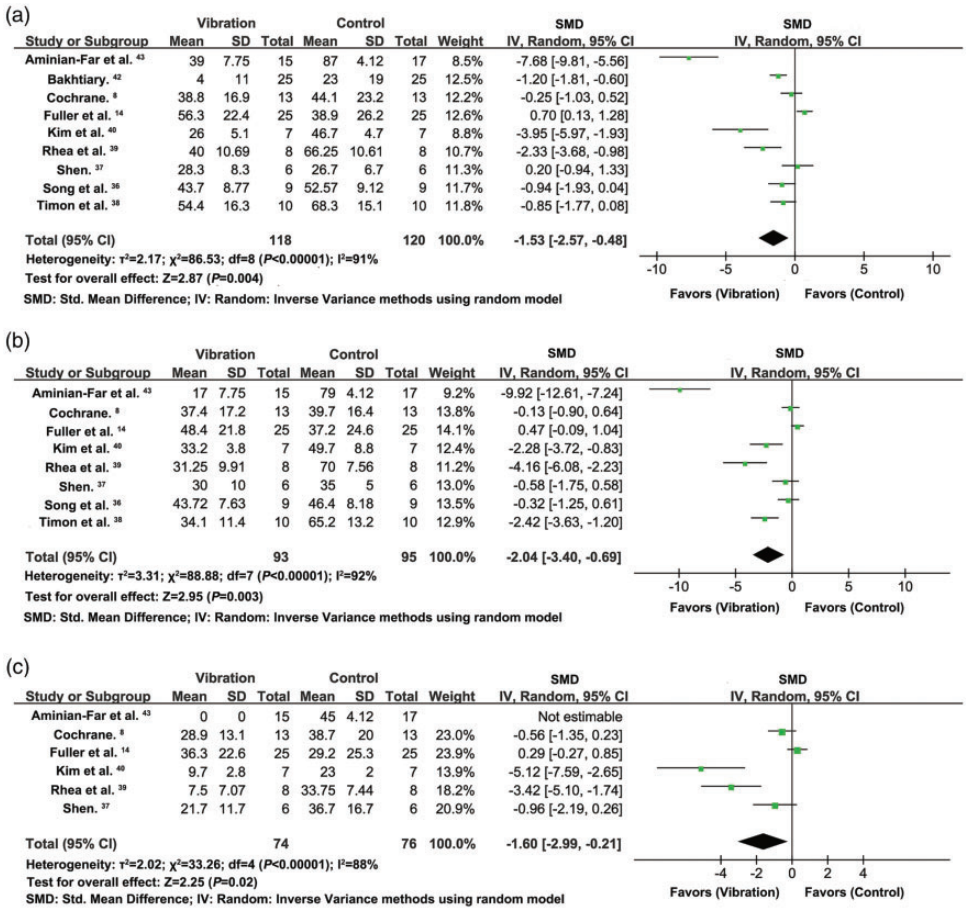

Figure 3. Effects of vibration on VAS at 24 (a), 48 (b), and 72 hours (c) after exercise

Subgroup analysis and sensitivity analysis

The above analyses demonstrated high heterogeneity ($I^2 > 50\%$). We therefore conducted sensitivity analysis to investigate the influence of each study. The total effect rating in terms of the primary outcome (VAS 24 hours) was stable when the included RCTs were removed one at a time ($I^2 > 50\%$) (Figure 5a). Meta-regression requires a minimum of 10 included studies, but the VAS 24 hours data was only based on nine studies and the planned meta-regression analysis was therefore not performed.

We further explored the source of the heterogeneity by subgroup analyses based on the primary outcome of VAS 24 hours, to detect potential clinical, statistical, and methodological heterogeneities. Subgroup analysis showed that the method of inducing DOMS, including downhill running/walking, and plyometrics and resistance training, contributed to the heterogeneity in VAS 24 hours (Figure 5b). Other subgroup analyses indicated that sex, region of study, type of vibration (WBV or LV),

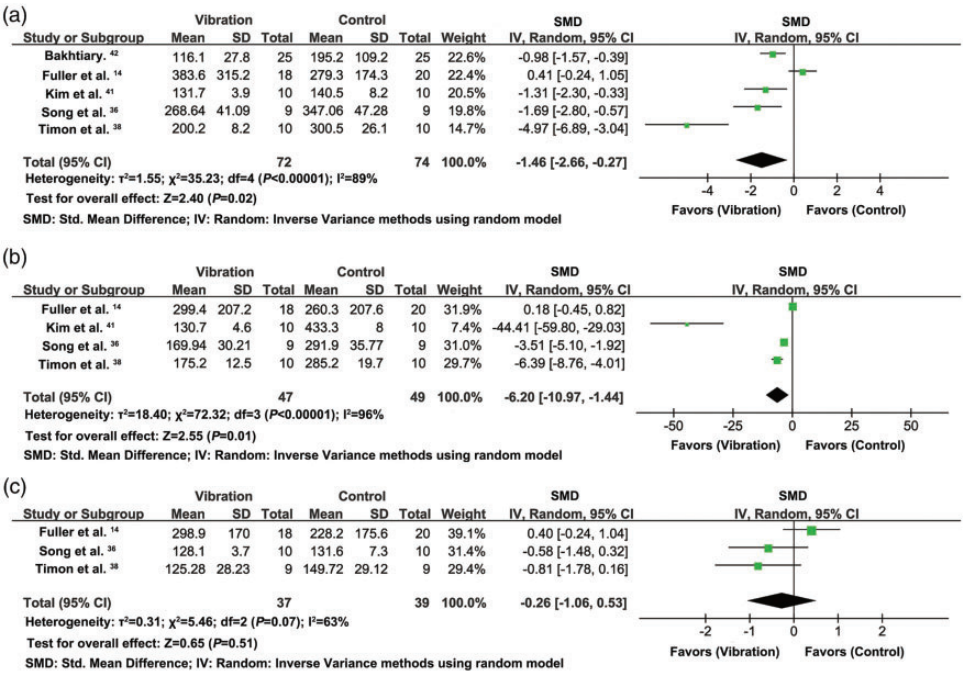

Figure 4. Effects of vibration on CK levels at 24 (a), 48 (b), and 72 hours (c) after exercise

vibration before or after exercise, frequency of vibration, amplitude of vibration, duration of each vibration session, total vibration duration, blinding, and concealment, did not contribute to the heterogeneity in VAS 24 hours.

Publication bias

Funnel plots require a minimum of 10 studies, but the primary outcome of VAS 24 hours was only measured in nine studies and publication bias could therefore not be assessed by this method or using Egger's test.

Discussion

The use of vibration to prevent and treat DOMS is growing in popularity in gyms and sports stadiums; however, direct evidence of its efficacy is still lacking. We searched four medicine, two physiotherapy and sports, and three Chinese databases and identified a total of 10 RCTs that investigated this issue.

The VAS is the direct pain index used by subjects to report DOMS, and is frequently assessed in clinical investigations of pain in patients with muscle pain and osteoarthritis, due to its convenience and reliability. The results of the current meta-analysis indicated that vibration reduced muscle pain at 24, 48, and 72 hours. Interestingly, the SMD of VAS at 48 hours following exercise was −2.04, which was greater than the changes at 24 (−1.53) and 72 hours (−1.60), suggesting that vibration treatment can achieve peak pain relief at 48 hours. An increase in CK levels commonly represents muscle fiber damage, during which CK is released into the lymphatic system and consequently into the serum. CK blood levels thus commonly represent a key marker of muscle damage and

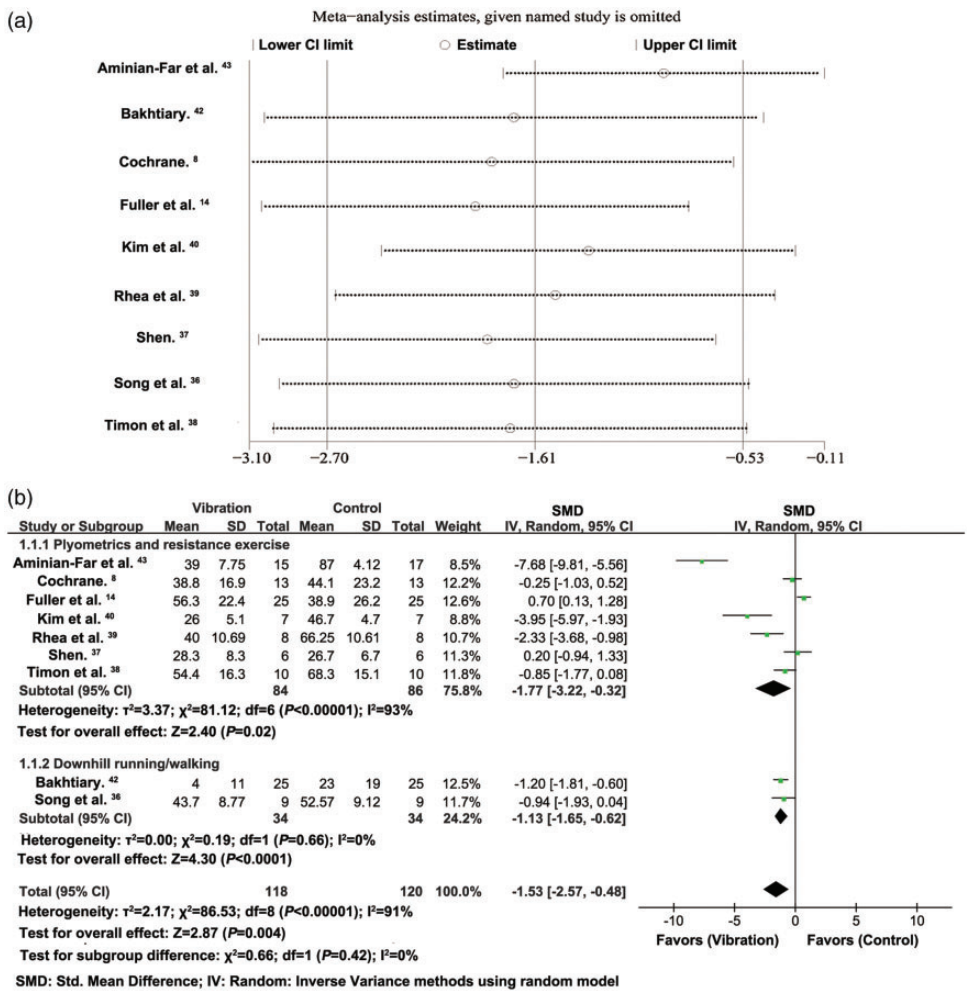

Figure 5. Sensitivity analysis (a) and subgroup analysis according to method of inducing DOMS (b) in relation to VAS 24 hours

injury.[18] According to this meta-analysis, vibration alleviated muscle damage and inflammation at 24 and 48 hours, consistent with the changes in VAS. The CK SMD at 48 hours was −6.20, which was greater than the change at 24 hours (−1.46), supporting the idea that vibration had the greatest benefit in terms of relieving pain and down-regulating CK levels at 48 hours after exercise. To the best of our knowledge, the current study represents the first meta-analysis to investigate the efficacy of vibration for DOMS, based on more credible quantitative results compared with an earlier descriptive systematic review.[19]

Some of the studies included in this meta-analysis increased the risk of heterogeneity. Subgroup analysis indicated that the method of inducing DOMS, including downhill running/walking, and plyometrics and resistance training (Table 1),[42] contributed to the heterogeneity in VAS at 24 hours. The I^2 values for VAS and CK at 24 hours in the downhill running/walking

subgroup were 0% and 18%, respectively. The mechanism responsible for DOMS is currently unclear. Asmussen proposed that lengthening (eccentric) but not shortening (concentric) muscle contraction was the primary factor causing DOMS.[45] Plyometrics and resistance exercise frequently use eccentric exercise to induce DOMS, resulting in pain, fatigue, and increased CK levels, while downhill running or walking can also elicit DOMS.[46,47] However, a recent report suggested that the hamstrings did not perform an absolute eccentric muscle action during the swing phase, especially in running.[48] Furthermore, the plyometrics and resistance exercise methods that induced DOMS differed among the studies included in the exercise subgroup (Table 1), which may be responsible for the high heterogeneity in this subgroup. Further clinical studies should thus be conducted with consistent methods of inducing DOMS.

The current study had some limitations. First, the number of included studies was relatively small. However, DOMS is usually only elicited by excessive sports participation and thus commonly occurs in athletes and fitness enthusiasts, but not in other individuals. Furthermore, the doctors in the included trials were not blinded, or were only single blinded, but this was likely because the rehabilitation process (i.e., vibration) would be evident to the participants, in contrast to the situation in trials of internal medication. The relatively small sample size and the lack of blinding meant that the quality of the evidence in this meta-analysis was relatively poor, and further large-scale, blinded RCTs are needed in the future.

Additionally, the pressure pain threshold (PPT) is frequently used as an index for rating the intensity of muscle pain,[49] but differences in the units used to measure PPT in the current literature meant that it could not be used in the current analysis. For example, PPT was recorded in N,[8] Kpa,[15] or kg/cm,[40] and varied in numerical values at different ranges and locations.[41–43] Furthermore, the range of motion was explored in different joints, including the knee in two studies[15,36] and the elbow in one.[8] Furthermore, other strength, movement, and electromyography indexes were lacking or differed among studies in the present literature. Further large-scale RCTs should thus include consistent measurement indexes.

Conclusion

In conclusion, we demonstrated that vibration intervention could alleviate DOMS and reduce serum CK levels, based on a meta-analysis of 10 RCTs including 258 participants. Vibration may therefore be a beneficial and useful physiotherapy for alleviating DOMS. However, the quality of the existing evidence is relatively poor, and future large-scale, blinded RCTs using unified units and consistent methods of inducing DOMS are needed to clarify the role of vibration in patients with DOMS.

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Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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