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Effect of whole-body vibration combined with an exercise program in females with chondromalacia: A randomized controlled trial

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ABSTRACT

The aim of this study was to assess the influence of whole-body vibration (WBV) training combined with an exercise program on both pain and quadriceps isometric muscle force in adult females with chondromalacia patellae (CMP). This study employed a randomized controlled design with 40 healthy older female volunteers. Participants were divided into two groups: 20 in the whole-body vibration (WBV) group and 20 in the exercise (EX) group. The WBV group underwent a 4-week WBV training program, 3 times a week, alongside exercise, while the EX group participated in a 4-week exercise program without WBV. Primary outcomes, assessed at baseline and after 4 weeks, included pain intensity measured using a visual analogue scale (VAS) and quadriceps isometric muscle force measured by a Hand Held Dynamometer. The WBV training group exhibited significantly greater enhancements than the EX-group in terms of mean values and percentage changes in pain intensity and quadriceps isometric muscle force. The addition of WBV to exercise yields significantly superior outcomes compared to exercise training alone in CMP. The observed disparities between the WBV training group and the EX-group underscore the efficacy of WBV as a potent physical therapy intervention for the rehabilitation of CMP patients, particularly in enhancing strength gains and decreasing pain.

KEYWORDS

Whole Body Vibration; Chondromalacia Patellae; Strengthening Exercises

1. INTRODUCTION

Patellofemoral joint dysfunction currently accounts for the majority of acute and chronic knee problems diagnosed in orthopedic and physical therapy clinics (Petersen et al., 2014). Anterior knee discomfort affects 22 out of every 1,000 people annually, which is a high occurrence (Petersen et al., 2013), compared to men, women have a 2.23-fold higher risk of developing it (Boling et al., 2010).

Chondromalacia (CM) affects the hyaline cartilage covering the bone's articular surfaces. Hyaline cartilage covers the lower part of the patella, and this cartilage articulates with the femoral groove (also known as the trochlear groove). This cartilage becomes softer, tears, fissures, and erodes. It is most frequently understood to involve the knee's extensor mechanism, which is why it is also known as runner's knee, patellofemoral syndrome, or chondromalacia of the patella. There are four grades of chondromalacia, which can affect any joint but is more common in stressed and deformed joints like the knee and patella: Grade 1 cartilage lesions manifest as softening, swelling, and edema; grade 2 involved fragmentation and fissuring in a half-inch-diameter or less; grade 3 involved the same lesions as grade 2, but the affected area is larger; and grade 4 involved cartilage denudation, erosion of the cartilage down to the subchondral bone, and proliferation (Habusta, 2023).

Effusion, quadriceps wasting, and retropatellar crepitus are examples of physical indications of chondromalacia patellae (CMP), that have been suggested to be more useful in the identification of the condition (Zheng et al., 2021). However, the most reported knee symptom is a dull aching pain around the patella in the peripatellar area, localized to the front of the knee (Petersen et al., 2014). These symptoms generally recur after descending stairs (eccentric quadriceps contraction), deep knee bends, sitting with knees flexed 90° or more for long periods of time, and repetitive flexion/extension exercises with chronic overloading (Dursun et al., 2022).

The diagnosis of CMP is usually based on these symptoms and a variety of noninvasive diagnostic tests to rule out other causative factors (Ficat & Hungerford, 1977; Install, 1982; Krompinger, 1983; Fox, 1988). Pain and discomfort during squatting is the most sensitive physical examination finding (Gaitonde et al., 2019). The treatment of chondromalacia remains varied and controversial (Petersen et al., 2014).

Whole-body vibration (WBV) is a relatively new exercise modality gaining interest in rehabilitation centers predominantly because of the reported impacts of vibration on the neuromuscular and neuroendocrine systems (Cardinale & Wakeling, 2005). This exercise typically involves individuals performing traditional resistance exercises on the platform with their body mass as resistance. It has been shown that mechanical vibrations applied to the muscle or tendon stimulate sensory receptors, mainly length-detecting muscle spindles (Hagbarth & Eklund, 1966).

Several experimental studies have demonstrated the effect of WBV on muscle activation with virtually all reporting an increase in electromyogram (EMG) amplitude with the addition of vibration to various exercises (Lienhard et al., 2015; Dong et al., 2020; Arora et al., 2021; Monteiro-Oliveira et al., 2022; Woo et al., 2022; Colson et al., 2023) Whole-body vibration has been suggested to elicit a high degree of muscle activation (Dong et al., 2020). The mechanical stimulus of vibration transmitted to the body stimulate muscle spindles which activate the alpha motoneurons and starts muscle contraction similar to the "tonic vibration reflex".

The impact of WBV on the neuromuscular properties of skeletal muscles and spinal mechanisms is exhibited by an electromechanical delay, increasing rate of power improvement and the pre-synaptic inhibition of skeletal muscles (Hong et al., 2010). and there was significant improvement in maximal oxygen consumption (VO2) both during and following an acute WBV exercise session contrasted with a same exercise session without vibration (Hazell & Lemon, 2011) and WBV is effective for inducing a small degree of post activation potentiation (Cochrane et al., 2010; McBride et al., 2010). We therefore hypothesize that the addition of WBV to strengthening exercises will result in a larger muscular performance, decrease pain and decrease the symptoms of chondromalacia patellae compared to an identical exercise program performed in absence of vibration.

Therefore, the aim of this study is to investigate whether the whole-body vibration (WBV) combined with strengthening program improve muscle strength, decrease pain on patients with CMP compared to an identical exercise program without vibration.

2. METHODS

2.1. Design and participants

This was a single-blind, randomized, controlled study which was designed to investigate the effects of whole-body vibration exercise program combined with exercise program on chondromalacia patella, and the study involved two randomized groups in a pretest-posttest design.

Forty older healthy female volunteers were selected to participate in the study, their ages ranges between 20 to 25 years. The inclusion criteria were chondromalacia patella, normal body mass index (BMI) ranges from 18-25. Exclusion criteria were smokers, athletes, age less than 20 years; prosthesis; any neurological, musculoskeletal, or other chronic disease; a recent fracture or bone injury; and any medication that could affect strength adaptations and adversely affect the results of the study. Before giving their informed consent to participate, every participant was given a thorough explanation about the training and test protocol, goals, risks, and methods of the research. The Biomedical Research Ethics Committee of Umm Al-Qura University has approved and declared this research ethically feasible (Approval Number: HAPO-02-K-011-2023-11-1980).

2.2. Randomization

Participants were randomized into two groups consisting of 20 participants in the WBV group and 20 Participants in the EX-group. The randomization was performed simply by assigning a specific identification number to each patient.

Participants in whole body vibration (WBV) group they received whole body vibration training program (Table 1) plus exercise program (Warm up, strength, stretching exercise for lower limb muscles, resistance exercise), and participants in exercise (EX) group underwent the same exercise program without vibration training. All participants in this study follow exercise guidelines.

2.3. Evaluation and Intervention

Pain intensity assessment

Visual analogue scale (VAS) was used to evaluate pain. A 10-cm VAS was applied to quantify the average amount of pain, it is a reliable, accurate, valid, and sensitive instrument for assessing pain intensity. It scored from 0 to 10 cm, where 0 is pain free and 10 is maximal pain. Each Subjects was asked to mark a point on the line between 0 and 10 that related to his or her level of pain during the weeks of evaluation. Each Subjects was evaluated at baseline and after 4-weeks of treatment period. Greater pain intensity is demonstrated by higher rating (Baxter, 2003).

Evaluation of quadriceps isometric muscle force

Bilateral strength and power of the quadriceps muscle were measured using Hand Held Dynamometer (MIE, Medical Research Ltd, England) (Youssef et al., 2016). From a relaxed sitting position at the edge of the plinth with tested knee maintained in 90°of flexion. The handheld dynamometer was placed against the anterior aspect of the leg away from chin of tibia.

Examiner stood on the contralateral side to tested knee. Correct starting position by adjusting by dynamometer before testing was determined. Each patient was asked to exert maximal force and push his or her leg up by performing knee extension against the probe of the handheld dynamometer. The maximal isometric strength appeared automatically on the dynamometer screen (Ebid et al., 2012).

Whole body vibration training protocol

The participants in the WBV group were exposed to vertical sinusoidal WBV using (Power Plate International, Irvine, CA, USA) (Alghadir et al., 2018). The frequency used was set at 30 Hz and gradually increased until it reached 45 HZ with peak-to- peak amplitude ranging from 4 to 7 mm.

The training intensity and volume increased according to the overload principle. Training volume progressed by systematically increasing the duration of vibration sessions. Training intensity was increased by progressively raising the frequency (Hz) and incorporating dynamic lower limb exercises. The interventions consisted of two sessions per week for a total period of four weeks.

Patients in the WBV group started with a warm-up by walking on a treadmill for three minutes at a velocity of 4 km/h. The total duration of the whole-body vibration (WBV) training stimulus was 3 minutes, followed by a three-minute rest period. The frequency of vibration was set at 30 Hz in the first week and gradually increased to 35,40, 45 Hz by the fourth week. All subjects were asked to stand in a squat position on the vibration platform with their knees bent at 40 degrees in the first week, and this angle gradually increased to 50, 55, 60 degrees by the fourth week. This progressive overload is displayed in (Table 1).

Table 1. Training Volume and Training intensity of the Whole-Body Vibration (WBV) Program

	Sets	WBV Duration (s)	Rest (s)	Amplitude (s)	Frequency (Hz)	Exercise	Knees angle
Week 1	2	180	180	4	30	SWBK	40̊
Week 2	2	180	180	4	35	SWBK	50̊
Week 3	2	180	180	5	40	SWBK	55̊
Week 4	2	180	180	7	45	SWBK	60̊

Note. SWBK= standing with bent knees.

2.4. Training program

The interventions consisted of three sessions per week for a total period of four weeks. Participants in the WBV group started with a warm-up by walking on a treadmill for three minutes at a velocity of 4 km/h. The total duration of the whole-body vibration (WBV) training stimulus was three minutes, followed by a three-minute rest period. The frequency of vibration was set at 30 Hz in the first week and gradually increased to 35 Hz, 40 Hz, and 45 Hz by the fourth week. All subjects were asked to stand in a squat position on the vibration platform with their knees bent at 40 degrees in the first week, and this angle gradually increased to 50 degrees, 55 degrees, and 60 degrees by the fourth week.

Both the WBV and EX groups performed the following exercise program, which includes active strengthening exercises for the quadriceps, as well as hip abductors, lateral rotators, and extensors:

- *Warm up by walking for 3 minutes on a treadmill.*
- *Banded Leg Extension Exercise (Isometric):* Participants sit on a chair and place a resistance band around their ankles. They extend one leg forward, straightening the knee and lifting the foot off the ground. They hold the extended position for 30-45 seconds, then return to the starting position. Aim for three sets of 30-45 seconds twice a week.
- *Banded Glute Bridge:* Participants lie down on the floor with their back straight against the ground and their knees at right angles. They place a resistance band around both thighs, just above the knees. Keeping their arms at their sides, they press their knees out against the bands and raise their hips towards the ceiling, squeezing their muscles tight and holding for 2-3 seconds. Aim for three sets of 10-15 repetitions.
- *Banded Clam Shell:* Participants place a resistance band around their knees and lay sidewise on an exercise mat with their knees together, pointing forwards and bent at a 90-degree angle. Keeping their feet in a fixed position, they lift their upper knee about 8-10 inches away from their lower knee and hold this extended position for 2-3 seconds. Aim for three sets of 10-15 repetitions.
- *Side-Lying Quadricep Stretch:*Participants lie on their side and bend the knee of their top leg as far as they are able, gently pulling with their hand. They maintain this position for 30 seconds. Each participant had four bands in different colors, with each color symbolizing a specific intensity. The intensity of the bands gradually increased, starting with the least intense band in the first week and gradually increased the intensity. During the first training session, all subjects were individually instructed on how to perform the vibration training (WBV group) and exercises. Additionally, subjects were supervised throughout all 12 sessions.

2.5. Outcome measures

The primary measure, in the form of pain score and quadriceps isometric muscle force were assessed at both baseline and the conclusion of the 4-week intervention period.

2.6. Statistical analysis

The SPSS software package (version 16.0; SPSS Inc., Chicago, IL) was used for statistical computations and analysis. The Shapiro-Wilk test was used to determine whether the data were normal.

The mean and standard deviation of the data were displayed. The paired t-test was used to compare mean changes in gait characteristics and postural stability indices (PSI) within groups. To assess variations amongst groups, the unpaired t-test was utilized. $P<0.05$ served as the threshold for significance.

3. RESULTS

Fifty participants were considered eligible to participate in this study (Figure 1). Three of those individuals refused to participate in the study, while seven of them were excluded because they failed to fulfill the criteria for inclusion. A total of 40 participated in this study.

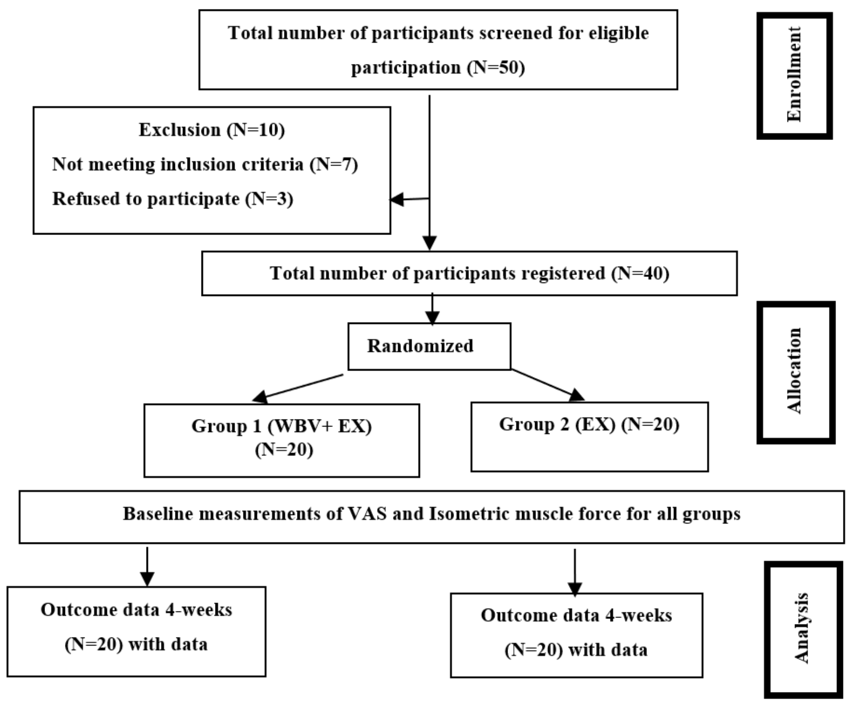

Figure 1. Flow chart of the study

At the beginning of the training period, there were no differences between the two groups with regard to of age, height, weight, BMI, affected sides, or duration of the complaint. There are no statistically significant differences in these variables among the groups, as shown in Table 2 ($p>0.05$). Baseline VAS (Table 3) and isometric muscle force (Table 3) were not significantly different between both groups ($p>0.05$).

Table 2. Demographic characteristics of participants (n=40)

	Group 1 (WBV+ Exercise program) (N=20)	Group 2 (Exercise program) (N=20)
Age (years)	21.7±0.82	20.7±0.67
Height (cm)	161.6 ± 5.70	160.7 ±.5.19
Weight (kg)	51.5 ± 6.88	50.50 ± 5.84
BMI (kg/cm^2)	19.7 ± 1.65	19.6 ± 1.60
Affected side	7 left, 8 right, 5 both	8 left, 9 right, 3 both
Duration (years)	4.15 ± 1.01	4.50 ±1.15

Note. BMI: body mass index; There were no significant differences between both groups.

Table 3. Mean values of pain intensity and quadriceps muscle force muscle force at baseline and after 4-weeks within each group and between groups

Variables	Time	Group 1 (WBV+ Exercise program) (N=20)	Group 2 (Exercise program) (N=20)	T value	P value
Pain scale (VAS)	**Baseline**	2.50±1.178	2.8±0.918	0.635	0.533**
	4wk	1.01±1.189	1.2±0.93	0.563	0.576 **
	P value	0.015*	0.0011*		
	T value	2.815	3.872		
	% of change	60%	57%		
Quadriceps isometric muscle force	**Baseline**	10.99±0.948	11.8±2.002	1.156	0.262**
	4wk	15.52±0.970	13.6±1.35	5.165	<0.0001*
	P value	<0.0001*	0.0299*		
	T value	10.56	2.357		
	% of change	41%	15%		

*Note. WBV: whole body vibration, VAS: visual analogue scale; Values are mean ± SD; ** Non-significant; * Significant.*

The WBV and EX groups showed a significant difference in post-treatment VAS score and quadriceps isometric muscle force results compared with the baseline values (Table 3 & Figure 2 & 3). The VAS scores significantly decreased after 4-weeks for both groups, but the WBV group is significantly lower than the EX-group at 4-weeks (Table 3). Quadriceps isometric muscle force significantly increased after 4-weeks for both groups, while the significance was higher in the WBV group as compared with the EX-group (Table 3).

However, distinct differences in the averages of quadriceps isometric muscle force and pain score between the WBV and EX groups emerged at both the initial assessment and the 4-week ($P < 0.05$). Notably, participants in the WBV group exhibited more substantial enhancements in their quadriceps isometric muscle force than those in the EX-group. Additionally, the (WBV) group demonstrated a significantly greater percentage of change of pain intensity and quadriceps isometric muscle force than the EX-group, as displayed in (Table 3, and Figures 4 & 5).

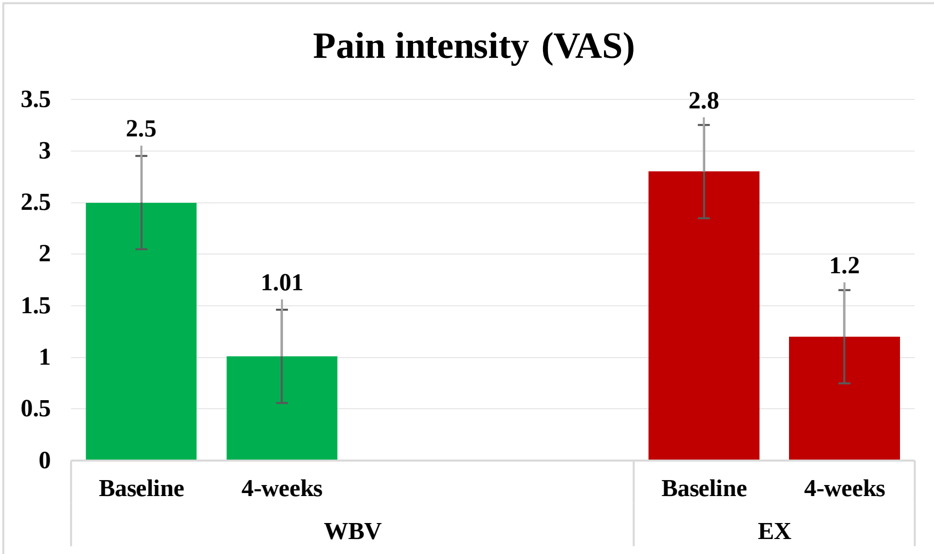

Figure 2. Mean values of pain intensity at baseline and after 4-weeks within each group and between groups

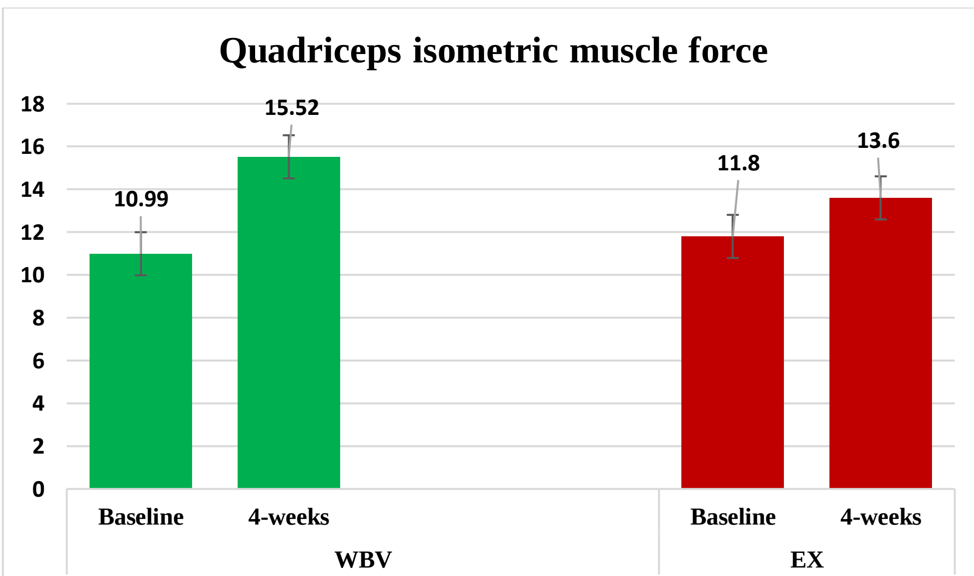

Figure 3. Mean values of quadriceps isometric muscle force at baseline and after 4-weeks within each group and between groups

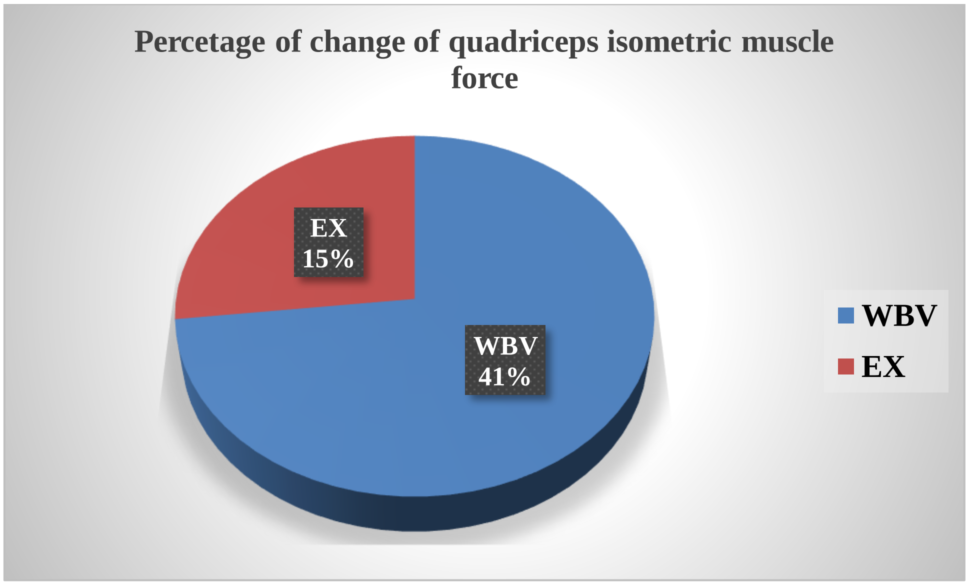

Figure 4. Percentage of change of pain intensity between groups

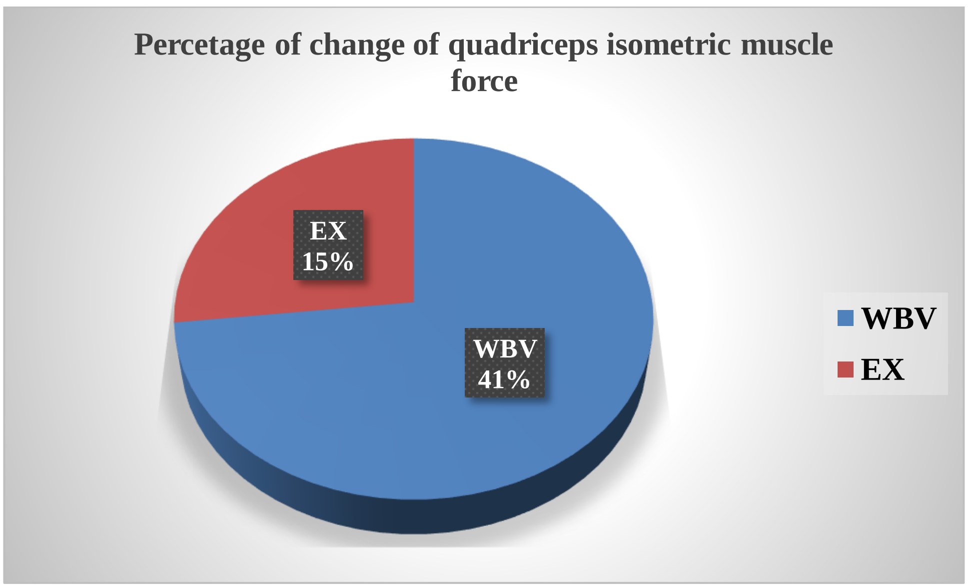

Figure 5. Percentage of change of quadriceps isometric muscle force between groups

4. DISCUSSION

This study was designed to test whether the combination of WBV and physical therapy exercise program has any additional effect on knee extensor muscle strength and pain compared to an identical exercise program without vibration on patient with chondromalacia patella. The primary finding of this randomized, controlled study is that whole body vibration and exercise decreases pain and increases isometric muscle force in female with the chondromalacia. To our knowledge, this was the first review to focus on lower limb strength training and pain for patients with chondromalacia patella.

The result of this study showed that 4-week WBV with exercise had additional positive effects on pain, and isometric strength of knee extensors in patients with chondromalacia patella, compared with a control group performing strengthening exercises alone. More importantly, no adverse outcomes were reported for WBV.

It is well known that vibration exercise enhances muscle strength (Alghadir et al., 2018). although the exact mechanism is unclear. Studies have suggested that whole-body vibration influences neuromuscular adaptation (Simao et al., 2019). and therefore, improves muscle strength. The oscillating platform's vibration can stimulate muscle spindles, which in turn can activate the alpha motor neuron and cause the tonic reflex to vibrate (De Gail et al., 1966; Tankisheva et al., 2013) and spinal and supra-spinal mechanisms.

Many studies had shown that Vibration therapy have multiple effects on muscle strength, postural control and balancing ability (Leung et al., 2014; Wong et al., 2020) similar to exercise, WBV can have effects on the central mechanisms, cortical reorganization and nociceptive activity, and therefore reduce pain and improve muscle strength. Therefore, several studies have considered vibration therapy as a type of exercise therapy (Ahlborg et al., 2006; Pistone et al., 2016; Dong et al., 2019).

Whole body vibration has recently been suggested as an alternative or replacement for traditional training methods in the mean of strength training for the elderly and various musculoskeletal disorders (Wysocki et al., 2011; Horstmann et al., 2013; Simao et al., 2019). In our study, compared with similar strength training, WBV training significantly increased the muscle strength in patients with chondromalacia patella. Several reasons can explain the increased effect of WBV training on muscle strength. First, when standing on the oscillating platforms during WBV, the person's body is subjected to mechanical stimulation; this stimulation is then conveyed to the muscle spindles' primary terminals. The "tonic vibration reflex," which is one type of muscular response brought on by the activation of muscle spindles, mediation of Ia afferents, and activation of muscle fibers, is triggered by vibration and results in a change in the length of the muscle tendon complex in skeletal muscle (Cardinale & Bosco, 2003; Park et al., 2013). Second, the force during strength training is dependent on the acceleration of gravity and mass. But for the WBV group, the vibration of the platform altered the acceleration, modifying the resistance throughout training sessions and maybe improving muscular strength.

Significant changes in pain, physical functioning, and knee extensor strength were linked to whole-body vibration (Qiu et al., 2022). Long-term of WBV training has been proven to improve patients with musculoskeletal problems in terms of pain control, muscle strength, and functional performance (Moura-Fernandes et al., 2020).

In our study, compared with similar strength training, WBV training significantly improved pain in patients with chondromalacia patella. WBV therapy enhances pain perception and other senses. According to Melzack & Wall (1965), the gate control theory of pain provides a legitimate explanation for how WBV lessens pain." The gate-control theory of pain inhibition primarily explains the mode of action of these techniques, " state Longe et al. (2001) in which small diameter nociceptive afferents (C fibers) experience less pain due to the activation of local inhibitory circuits in the substantia gelatinosa of the dorsal horn via Aβ fibers, large diameter sensory fibers conducting impulses from the selective activation of low threshold mechanoreceptors." Consequently, presynaptic inhibition of nociceptive inputs at the spinal cord's dorsal horn is how WBV reduces chronic pain. On the other hand, based on the hypothesis of pain gate control, it is likely that a single WBV session resulted in a reduction in pain intensity by blocking the peripheral nervous system's sensations. The reduction in pain intensity may be explained by the rapid effects of WBV, which some researchers have linked to increased blood flow and skin warmth (Sohrabzadeh et al., 2021).

Chondromalacia patellae reduce the functional ability and muscle strength of the knee. Exercises have gained popularity as a category of exercises for the rehabilitation of chondromalacia patella because they can elicit maximal VMO firing, particularly between 0 and 60 degrees of knee flexion (Kettunen et al., 2005). According to Nascimento et al. (2018), PPS patients who had conservative treatment using exercises to strengthen the associated hip and knee muscles experienced better outcomes and results, such as decreased pain and improved functional activities, compared to exercises that aimed only to strengthen the local stabilizers of the knee. This is because, in addition to stabilizing the pelvis during movement, the gluteus medius (GMed) muscles also promote hip abduction and control the internal rotation of the femur. WBV with strengthening exercises showed additional effects on knee extensor isometric muscle strength43. The current study also found that WBV combined with strengthening exercise was more effective for improving knee extensor strength, whereas there was a limited effect on knee flexor strength. The position of participants on the vibratory platform may be responsible for this difference (Qiu et al., 2022). Most participants in the study had slight flexion of the knees on the vibration platform and therefore the quadriceps were stretched which explains the increased response to vibration (Qiu et al., 2022).

Stronger muscles and improved knee function were two benefits of the strengthening exercise program conducted in our study. The improvement of the range of motion (ROM) of knee extension occurred as a consequence of pain reduction which is responsible for improvement in muscle function. In the current study the pain intensity was determined by VAS, which is valid, reliable and commonly used assessment tool of pain (Baxter, 2003).

Because lower limb muscle training can reduce knee pain and enhance physical function, it has gained attention as an inexpensive treatment option for musculoskeletal disorders (Bennell et al., 2007). A study has shown that people with PFPS, strengthening the quadriceps should be a key component of their treatment as a result, there is solid proof that the combination of strengthening the quadriceps and other therapies reduces pain more effectively (Bennell et al., 2007). The level of pain was reduced only in WBV combined with EX program, the mechanism involved in the reduction of pain can be explained according to vibration-induced sensory inhibition related to peripheral (a sensory inhibition would be linked to the gate control theory of pain) and central levels justified by the stimulation of areas responsible for processing pain and vibrotactile sensations in the somatosensory cortex of the brain (Moura-Fernandes et al., 2020). When it comes to reducing pain and increasing activity in people with patellofemoral pain, hip and knee strengthening is more beneficial than knee strengthening alone (Nascimento et al., 2018). In individuals with PFP, short- and long-term pain relief and improved knee function were obtained by exercises focused on strengthening the quadriceps and hip muscles (Alammari et al., 2020).

There is a limitation of our study, our study sample consisted of a relatively small, homogenous group of subjects (females with weak knee extensors and pain) and relatively short measurement and training periods. Whether or not the results of the current investigation may be generalized to other populations with chondromalacia patella (e.g., males and those with acute symptoms) remains to be seen.

5. CONCLUSIONS

The results of the current study clearly demonstrated that the combination of an exercise program and WBV training program for a duration of 4-weeks led to a significantly greater improvement compared to exercise training alone in the treatment of CMP. The findings revealed significant differences between the group that underwent WBV training and the group that only received exercise training. These results indicate that WBV can be considered as an effective physical therapy method for the rehabilitation of Chondromalacia Patella patients, particularly in terms of strength gains.

6. RECOMMENDATIONS

In light of the research findings, the following specific recommendations are provided for future researches:

- Integration of Whole-Body Vibration (WBV) with Exercise: Incorporating a whole-body vibration training program along with exercises program can be beneficial for individuals with CMP. This combination approach may lead to further improvements in pain management, physical function, knee mobility, and quadriceps strength.
- Comparative Studies: Comparisons between different interventions, such as comparing the effectiveness of WBV alone versus WBV combined with exercise, could offer insights into the relative benefits of each approach. Additionally, exploring the effects of WBV on larger samples and for extended durations could further elucidate its efficacy in managing chondromalacia patella.
- Longer-Term Studies: While this study spanned four weeks, longer-term investigations are recommended to assess the sustained effects of WBV combined with exercise on chondromalacia patella. This could provide valuable insights into the maintenance of improvements over time.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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