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The effect of whole-body vibration training on the lower extremity muscles' electromyographic activities in patients with knee osteoarthritis

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Abstract

Background: Whole-Body Vibration Training (WBVT) is a novel neuromuscular training method that has been recently developed as a rehabilitation tool. The purpose of this study was to determine whether WBVT is effective on electromyographic activity of the muscles of the lower limbs in patients with knee osteoarthritis.

Methods: The study was designed as a single blinded randomized clinical trial (IRCT201601171637N5), 45 patients with knee osteoarthritis were randomly assigned to three groups; WBVT (n = 15) receiving 12 sessions vibration therapy, control group (n =15) doing two exercise in the home and placebo (n =15) doing exercise like WBVT group on-off vibration system. Electromyographic activities of vastus lateralis and vastus medialis, semitendinosus, gastrocnemius and soleus were evaluated pre and post intervention. The paired-samples t-test and ANOVA were applied respectively to determine the differences in each group and among the groups ($P \leq 0.05$).

Results: The RMS value of vastus medialis in semi squat position in placebo group (p=0.024), vastus lateralis in SLR position in WBVT group (p=0.037), soleus in knee flexion in WBVT group (p=0.018), semitendinosus in knee flexion in WBVT group (p=0.007) and RMS response of Semitendinosus in ankle plantar flexion in control group (p=0.047) were revealed significant differences between the pre- and post- intervention. The ANOVA test confirmed the significant differences between the studied groups according to the EMG activity of vastus medialis in semi squat position (p=0.045), semitendinosus in semi squat position (p=0.046) and in plantar flexion position (p=0.015) and also soleus in plantar flexion position (p=0.003).

Conclusions: The findings of this study showed the beneficial effects of WBVT in the improvement of the muscles RMS values in the patients with knee OA especially muscles' progression rates in a four-week period.

Keywords: Knee osteoarthritis, Whole body vibration training, Electromyography, Randomized clinical trial

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Introduction

Knee Osteoarthritis (OA) is a degenerative osteoarticular disease with a multifactorial etiology. Knee OA is characterized by arthralgia, stiffness, and limitations of motion (1, 2). Knee OA , the most prevalent joint disorder, (1) is a major public health issue that causes chronic pain and disability among elderly worldwide. World Health Organization forecast that Knee OA will become the fourth primary cause of disability by the year 2020 (3). Epidemiologic studies have shown that the prevalence of knee OA with Kellgren–Lawrence(KL) grade 2 or higher was 30–40% in western countries, whereas the prevalence of knee OA is 60% or higher in Asian populations(4, 5). Davatchi et al. has shown a high prevalence of knee OA in an urban population of Iran (6). Many patients with knee OA are treated with a combination of non-pharmacologic, pharmacologic modalities and surgical treatments (7, 8). Each of these presents difficulties, especially when treating the elderly. Exercise therapy, for managing knee OA, offers numerous advantages such as increasing the knee range of motion, increasing the strength and endurance of muscles, improving

↑What is "already known" in this topic:
WHO forecasts that Knee OA will become the fourth primary cause of disability by the year 2020. There are recommendations that exercise therapy, especially quadriceps strengthening exercise, play role in osteoarthritis management.

→What this article adds:
Improvement in the muscles' RMS progression rate was seen in patients with knee OA during a four-week period of whole body vibration training (WBVT). The use of WBVT is still a good choice for training in senior and obese patients.

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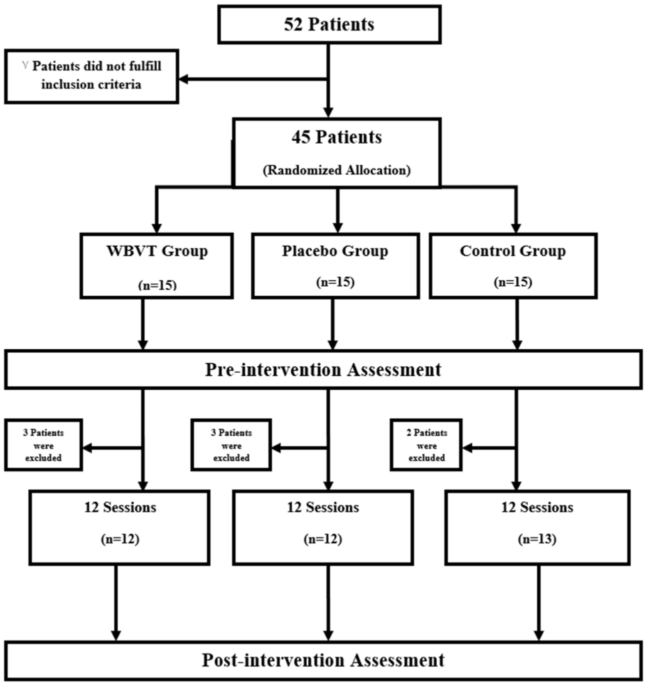

Fig. 1. Study profile for participants in WBVT and CT groups.

patient's balance, reducing the disability , improving the quality of life and etc (9,10). Many meta-analyses and systemic reviews support recommendations that exercise therapy, especially quadriceps strengthening exercise, is an important part in osteoarthritis management (11-15) because quadriceps weakness could lead to a decreased joint stability (16).

Unfortunately, many patients with knee OA are not able to exercise due to aging and obesity. Thus, there appears to be a need for additional viable, non-pharmacologic modalities to manage knee OA. Whole body vibration training (WBVT) is a kind of neuromuscular training that has received considerable attention recently as an exercise intervention because it seems to be easy and safe to perform.(17) WBVT has been reported as a helpful tool for elderly people (18). Therefore, WBVT can be prescribed for the patients with knee OA to strengthen the muscles in a very short time without doing any strenuous exercises(19). Previous studies have shown WBVT to be effective not only in increasing muscle strength and power, but also in improving balance and mobility, improving circulation, reducing fall risk and etc. in athletes, healthy people as well as different patients (20-23).

WBVT acts on proprioceptive receptors specially the muscle spindles which could initiate stretch reflexes, resulting in the activation of α motor neurons and causes muscle contraction; (20,24); thus, WBVT is an alternative to conventional exercise therapy for improving muscle strength and physical performance(25). WBVT could also improve postural stability due to its positive effects on muscle strength, synchronization of the motor units firing and improved co-contraction of synergist muscles, that might bring about better balance control strategies in patients(20). When exposed to WBVT, muscle contractions occur in order to absorb the vibration. The activity of muscles can also be analyzed by measuring the electromyography (EMG) signal. The lower leg muscles were the segment with the greatest stimulation during WBVT, as the EMG reached 5-50% of maximum voluntary contraction(26). The use of WBVT is still a new training modality, and there is little evidence with regard to the short-term effects of WBVT on muscle's activity in a patient with knee OA. Accordingly, this study was conducted to investigate the electromyographic (EMG) activities of lower extremity's muscles after receiving a four-week WBVT in patients with Knee OA.

Methods

The study was a single-blind, randomized clinical trial (IRCT registration number: IRCT201601171637N5) that was approved by the Ethical Committee of Tarbiat Modares University (no: 52/2521); and each subject provided informed written consent. Subjects were introduced to the Sport Physical Therapy Clinic, Faculty of Medical Sciences, Tarbiat Modares University, between April and December 2014.

Subjects

Fifty-two subjects participated in the study; the majority was referred by the research consultant orthopedic surgeon. Seven patients did not fulfill the inclusion criteria (severe OA on radiologic findings) and eight subjects were excluded (WBVT group, 3; due to radius fracture, travel, and personal business; placebo group, 3; due to tiresome, radius fracture and knee pain aggravation; control group, 2; due to heart disease and knee pain aggravation) at the next stage (Fig. 1).

Finally, 37 patients finished the study for one month. Also, during the study period, no other treatments, such as physical modalities nor injection technique were done to the patients.

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All patients fulfilled the following inclusion criteria: knee OA with Kellgren–Lawrence grade II and III in simple X-ray, between 55-75 years old, no previous or concomitant injury on the knee and other lower extremity joints, no previous history of serious knee trauma, surgery and arthroplasty, no history of knee intra-articular injection of hyaluronic acid or steroid in the last 6 months, no history of surgery or traumatic injuries to the lower limbs, no history of medical problems such as cardiopulmonary diseases, neurologic diseases, malignant diseases, chronic diseases such as diabetes, no history of newly repaired fracture and bone implants, no pacemaker and no history of WBVT contraindications (epilepsy, vertigo, uncontrolled hypertension, acute hernia, serious cardiovascular disease, pacemaker, acute thrombosis, tumors, recent surgery and fractures, hip and knee implants) for participants of the WBVT group. The exclusion criteria were acute symptomatic OA, taking any medication, any systemic disorder, incomplete treatment and assessment and WBVT intolerance for the WBVT group. A list of random numbers was generated using a computer. A numbered opaque sealed envelope containing the method indicator card was opened by the secretary of the department. Before pre-intervention assessment, the patients were randomly allocated to three groups: WBVT, placebo, and control (CT).

The power analysis of the study was performed to detect 10 differences in EMG RMS (mV) of vastus medialis with $\alpha=0.05$ and a power of 80, a sample size of 12 per group was required, due to drop-outs, we chose to include at least 15 subjects in each group.

Testing procedures

The surface electromyography (sEMG) is a technique to capture and measure electrical activity and muscle action potential and provide information regarding the neural activation of the muscles (27). The root mean square (RMS) value has been used as the method of choice to quantify the electric signal in this study because it reflects the physiological activity in the motor unit during contraction (28).

Participants were familiarized with the testing procedure one day before the evaluation session. In assessment sessions, each subject was dressed in shorts, without shoes and socks. Also, the EMG system was calibrated accordance with the manufacturer's instructions.

EMG Electrode Placement and Data Acquisition

The sEMG analysis procedures were performed in the quadriceps muscles (vastus lateralis and vastus medialis), hamstrings (semitendinosus, gastrocnemius and soleus) muscles by using four pairs of disposable bipolar surface (Silver/Silver Chloride) electrodes (Skintact, Austria). Two capture electrodes were placed on the belly muscles, always in the affected limb, and in the direction of the muscle fibers.

Numerous factors affect the quality of sEMG acquisition such as inherent noise in the electronic equipment, ambient noise in the surrounding atmosphere, motion artifacts and poor contact with skin. The first three factors are dependent on the sEMG acquisition system used and to reduce the effects of these, a DataLINK (Biometrics Ltd; UK) sEMG system (Fig. 2) was used. This system contains eight differential types of independent channels with high-pass filter of 10 Hz, and a low pass filter of 500 Hz to minimize interference with low-frequency noise that originates from the unwanted movement of cables and electrodes. The range of sampling frequency of DataLINK sEMG system per analog channel was between 10-5000 Hz; its bandwidth was +0 / -1dB up to 2.5 KHz with 0 to 4,950 mVdc power supply and 20 mA current supply per channel. The surface electrodes were a differential active-type (SX230 EMG sensor); with a diameter 4mm. The distance between the capture electrodes was 20 mm. In all evaluations, the reference electrode was kept on the anterior area of the opposite tibia. The capture time of muscular activity was performed during a period of 10 seconds. The usable energy in an EMG signal lies in the range of 0-500 Hz, and the acquired sEMG signal was digitized at 2000 samples per second using a data acquisition card and stored on a computer by the Biometrics Ltd Analysis Software version 8.51.

Fig. 2. DataLink surface EMG system and its electrodes

In order to have a good skin contact with the electrodes, the guidelines of European Recommendations for Surface Electromyography were followed (29). The skin of the patients was shaved and abraded with sandpaper and cleaned with 95% ethanol to reduce the impedance prior to the application of surface (self-adhesive) electrodes. The electrodes were placed at the desired locations after the skin was dried. The placement of the electrodes adapted for the analysis of the muscles was based on European Recommendations for Surface Electromyography; SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) (29).

For analysis of the vastus lateralis and medialis muscles, the patients were seated on a table, with knees in slight flexion, the ankle in the dorsiflexion and upper body slightly bend backward. For vastus medialis muscle, the electrodes were placed at an 80% imaginary line from the anterior superior iliac spine to the anterior border of the medial collateral ligament, and for vastus lateralis muscle, the electrodes

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were placed at an 80% imaginary line between the anterior superior iliac spine and the lateral side of the patella.

The analysis of the semitendinosus muscle was performed in the prone position at a 45º leg flexion and hip medial rotation. The electrodes were placed at a 50% imaginary line between the ischial tuberosity and the medial condyle of the tibia.

For analysis of the gastrocnemius, the patient was in prone position with knee extended and foot on a pillow to allow for ankle plantar flexion; the electrodes were placed at 1/3 of a line from the head of the fibula to heel.

The analysis of the soleus muscle was performed in seated position with knee approximately in 90° flexion and the heel and foot on the table. The electrodes were placed at 2/3 of a line from medial condyle of femur to medial malleolus.

The EMG signals were normalized in accordance with the maximum voluntary isometric contraction (MVIC) and recorded during a three second MVIC pre-intervention and post-intervention (30). Three trails of EMG evaluation in either condition were performed by one person (the first author), and patients had a 5 min rest between each condition. The signal accuracy and absence of noise was viewed during the recording.

The positions of EMG signal recording for the vastus medialis and lateralis were semi-squat and straight leg raising (SLR), and the positions for recording the semitendinosus, gastrocnemius, and soleus EMG activities were semi-squat, SLR, knee flexion (30 degrees according to the measurement by goniometer) and ankle full plantar flexion.

After the electromyographic activity capture, the RMS value of the EMG signal was used as a means for measuring the amplitude of the voluntarily elicited EMG signal. The RMS values, as the preferred method of normalization, were measured at the peak of activity during MVIC of the muscles (31).

Fig. 3. Fitvibe vibration system.

Interventions

After the pre-intervention assessment, subjects in the three groups began a three times a week training program for one month.

Whole body vibration training

The WBVT group did their intervention on a vibration platform (Fitvibe, Gymna Uniphy NV, Bilzen, Belgium) (Fig 3).

The WBVT program was done on the Fitvibe vertical vibration platform with an amplitude of 3 mm and frequency of 30 Hz. The patients were asked to stand barefoot on the platform with a 30-degree knee flexion (Semi squat) during training; the knee flexed position was controlled by a goniometer. The position was used to minimize the relative apparent mass magnitude, also for vibrations damping in the thigh region and no vibration transferring to the head (32, 33). In addition, the semi-squat position during WBVT resulted in an increased activation of the leg muscles especially vastus medialis (34).

To prevent the feeling of uncomforting and tiredness, the patient could hold a handle during training and the WBVT was designed as a progressive program.

The vibration training consisted of two set with three repetitions of one-minute WBVT and one-minute rest between repetitions and five-minute rest between the sets during the first week to avoid patients' muscles fatigue. Every week a set is added to the WBVT program so that the WBVT in the fourth week consisted of five sets.

Placebo Group

The patient in the placebo group did their intervention on a vibration platform as WBVT group while the vibration system was off and did not transmit any vibration to the patient's feet while standing in semi-squat position. Their protocol was similar to the WBVT group but without receiving vibration. The reason for designing a placebo group in this study was to evaluate the placebo and psychological effects of WBVT.

Control Group

The control (CT) group was educated to do exercises three set with ten repetitions and a five-second hold for a month in the home. The pause time between the sets was 60 seconds. The exercise program of CT group consisted of static contractions of quadriceps muscles and SLR. Each patient received a detailed handout containing instructions and photographs of the exercises. The patients were instructed that the pain should be avoided in all exercises, and also they are asked to refuse of doing any unusual physical activity and other exercises.

Statistical analysis

The SPSS (version 20, SPSS Inc, Chicago, IL) was used to conduct the analysis. Normal distribution of data was determined by One-Sample Kolmogorov-Smirnov test, and parametric tests were used to analyze the data. The paired sample t-test was applied to determine the differences in each group. The ANOVA and Tukey LSD test was used to

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Table 1. Subject characteristics

Variable	WBVT group (n=12)		Placebo group (n=12)		Control group (n=13)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	63.69	3.05	66.27	2.15	63.50	4.84
Weight (Kg)	83.14	15.01	85.14	11.90	82.71	12.80
Height (m)	1.71	0.06	1.69	0.06	1.67	1.618
BMI (kg/m2)	28.4	2.43	29.8	2.01	29.7	1.89
History of Knee OA (years)	9.05	1.58	7.47	1.02	8.67	2.34

compare the measurements between the groups and also to analysis change scores of all groups after the intervention. The change score of a group was defined as the increase or decrease of each variable from pre-intervention to post- intervention. The level of significance was set at $p \leq 0.05$. In order to study the improvement process of participants, the progression rate of all data was also calculated as the following equation.

$$Progression\ Rate = \frac{Post\ Intervention\ Mean - Pre\ Intervention\ Mean}{Pre\ Intervention\ Mean} \times 100$$

To assess the intra-tester reliability of objective tests, 15 healthy subjects had repeated measurements seven days apart in a pilot study. Test-retest reliability of EMG (RMS) activity of vastus medialis muscle in two positions, SLR and semi-squat, was assessed using interclass correlation coefficients (ICC) with a 95 level of confidence. ($p \leq 0.0001$). The ICCs between the first and second measurements were 0.994 and 0.996, respectively, for EMG RMS activity of vastus medialis muscle in SLR and semi squat position.

Results

There were no significant differences between WBVT, placebo and CT groups for the demographic variables listed in Table 1, indicating that the groups were well matched.

The statistical analysis ANOVA revealed no significant differences between the groups at the beginning of the study. The gender distribution of patients in the studied groups was as follows; WBVT group 50% (n=6) women, Placebo group 42% (n=5) women and CT group 38% (n=5) women.

In all groups, subjects became acquainted very rapidly with the training protocols. There were two reports of knee pain aggravation (one in the placebo group and the other in CT group) which led to the discontinuation of treatment and their exclusion of the study. But all subjects in the WBVT group found the vibration training to be an effective and tolerable modality for exercise therapy. The Tables 2 and 3 have been showed the RMS values (µV) of the vastus medialis, vastus lateralis, gastrocnemius, soleus, and semitendinosus muscles during MVIC in different positions. As seen in these tables, the paired-sample t-test revealed significant differences in vastus lateralis (SLR), soleus (semi squat) and semitendinosus (knee flexion) RMS values between pre and post intervention in WBVT group ($p \leq 0.05$). Also, there were significant differences in the vastus medialis (semi-squat) RMS values in the placebo group and the semitendinosus (ankle plantarflexion) in CT group between pre and post intervention.

Comparison between the groups

Between-group differences were analyzed using ANOVA on change scores of both groups after the intervention. The change score was defined as the increase or decrease of the variable from pre to post intervention. The ANOVA was

Table 2. Comparison of the pre and post intervention RMS values (µV) of the vastus medialis and lateralis muscles between the groups during MVIC in semi-squat and SLR positions.

Variable	WBVT group (n=12)			Placebo group (n=12)			Control group (n=13)		
	Mean ±SD Pre intervention	Mean ±SD Post intervention	P value	Mean ±SD Pre intervention	Mean ±SD Post intervention	P value	Mean ±SD Pre intervention	Mean ±SD Post intervention	P value
Vastus Medialis (Semi squat)	40.17 ± 33.58	57.33 ± 34.85	0.172	38.67 ± 31.67	57.42 ± 36.47	0.024*	43.92 ± 21.19	45.77 ± 20.45	0.799
Vastus Medialis (SLR)	55.25 ± 35.71	73.83 ± 65.69	0.141	52.33 ± 34.90	49.33 ± 33.92	0.400	60.92 ± 30.02	56.71 ± 25.59	0.280
Vastus Lateralis (Semi squat)	51.75 ± 28.44	47.92 ± 22.08	0.201	37.08 ± 21.03	41.75 ± 22.70	0.259	43.15 ± 21.62	42.71 ± 24.04	0.943
Vastus Lateralis (SLR)	68.67 ± 43.13	77.33 ± 49.57	0.037*	54.58 ± 25.57	50.58 ± 23.06	0.285	77.31 ± 40.01	78.08 ± 40.48	0.882

*Significant difference between pre-test and post-test values, p≤ 0.05.
MIVC: maximum voluntary isometric contraction

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Table 3. Comparison of the pre and post intervention RMS values (μV) of the gastrocnemius, soleus, and semitendinosus muscles between the groups during MVIC in different positions.

Variable	WBVT group (n=12)			Placebo group (n=12)			Control group (n=13)		
	Mean ±SD Pre interven-tion	Mean ±SD Post interven-tion	P value	Mean ±SD Pre interven-tion	Mean ±SD Post interven-tion	P value	Mean ±SD Pre interven-tion	Mean ±SD Post interven-tion	P value
Gastrocnemius (Semi squat)	19.92 ± 16.24	25.42 ± 24/14	0.212	21.08 ± 16/22	17.25 ± 10.98	0.379	20.85 ± 15.29	22.31± 15.00	0.752
Gastrocnemius (SLR)	14.33 ± 24.43	16.50 ± 21/59	0.240	5.00 ± 3.81	3.67 ± 3.65	0.480	13.85 ± 25.93	12.92± 17.31	0.803
Gastrocnemius (Knee Flexion)	64.58 ± 54.13	80.17 ± 62/36	0.093	44.42 ± 24/51	52.08 ± 28.03	0.425	40.31 ± 31.16	39.85± 34.75	0.958
Gastrocnemius (Ankle Plantarflexion)	56.67 ± 54.23	74.83 ± 53.23	0.147	43.67 ± 23.35	50.25 ± 23.87	0.297	58.15 ± 57.45	58.77± 51.49	0.922
Soleus (Semi squat)	26.00 ± 17.77	38.67 ± 18.95	0.018*	32.75 ± 19.62	35.58 ± 28.45	0.642	26.23 ± 10.11	31.01± 14.30	0.166
Soleus (SLR)	11.42 ± 18.74	24.75 ± 19.53	0.434	8.23 ± 10.23	7.33 ± 8.08	0.791	13.38 ± 15.28	13.08± 9.69	0.942
Soleus (Knee Flexion)	62.92 ± 43.32	95.67 ± 59.04	0.253	47.42 ± 31.86	49.83 ± 30.57	0.770	35.69 ± 25.50	53.54± 69.90	0.296
Soleus (Ankle Plantarflexion)	86.43 ± 10.09	103.51 ± 88.94	0.401	42.67 ± 23.40	59.17 ± 23.94	0.431	73.46 ± 54.18	54.23± 31.62	0.121
Semitendinosus (Semi squat)	15.92± 9.76	18.58± 6.50	0.216	15.00± 8.54	14.83± 5.99	0.910	18.01± 9.70	19.06 ± 11.32	0.460
Semitendinosus (SLR)	17.92± 8.26	20.50± 14.26	0.380	23.25± 27.47	11.83± 7.06	0.189	15.15± 8.36	14.92 ± 6.99	0.849
Semitendinosus (Knee Flexion)	46.50± 22.65	78.00± 52.20	0.007*	64.75± 67.19	61.92± 34.68	0.844	55.08± 46.69	58.69 ± 46.75	0.703
Semitendinosus (Ankle Plantarflexion)	23.25± 27.86	37.42± 33.60	0.187	18.67± 12.25	22.33± 21.47	0.384	42.15± 47.21	47.85 ± 53.16	0.047*

*Significant difference between pre-test and post-test values, p≤ 0.05.

used to find out significant differences among the groups due to the normal distribution of the data. Also, the Tukey-LSD test was used to compare the post-intervention data between every two groups. The results of the comparison among the groups were expressed in the following according to the position of the recording of the EMG data.

Semi squat position

The ANOVA analysis showed no significant difference among the groups in the RMS values of the vastus medialis (p=0.453) and lateralis muscle (p=0.283). A significant difference was shown in the RMS values of the semitendinosus muscle (p=0.046), the Tukey-LSD test revealed the significant difference between the placebo and WBVT groups (p=0.037). The ANOVA analysis also showed no significant difference among the groups in the RMS values of the gastrocnemius (p=0.328) and the soleus (p=0.057).

SLR position

The ANOVA analysis showed no significant differences among the groups in the RMS values of the vastus medialis (p=0.352), the vastus lateralis (p=0.316), the semitendinosus (p=0.081), the gastrocnemius (p=0.192) and the soleus (p=0. 462).

Knee flexion position

The ANOVA analysis showed no significant differences among the groups in the RMS values of the semitendinosus (p=0.112), the gastrocnemius (p=0.201) and the soleus (p=0. 212).

Ankle plantar flexion position

The ANOVA analysis did not show significant differences among the groups in the RMS values of the gastrocnemius (p=0.142). But, a significant difference was shown in the RMS values of the semitendinosus muscle (p=0.015), the Tukey-LSD test revealed a significant difference between the placebo and WBVT groups (p=0.018) and also a significant difference between the CT and WBVT groups (p=0.009). The ANOVA analysis showed significant differences among the groups in the RMS values of the soleus (p=0.003), the Tukey-LSD test revealed the significant difference between the placebo and CT groups (p=0.018) and also the significant difference between the CT and WBVT groups (p=0.003).

In order to do an accurate comparison of the groups, Table 4 showed the progression rate of the RMS values of the studied muscles. As seen shown in Table 4, the improvement in WBVT group was far more dramatic than the others, even in the values that there were not significant differences.

Discussion

Whole body vibration is a new kind of somatosensory training (20) and its effect on the strength of muscles have been demonstrated in various studies in healthy subjects (15, 35, 36). Thus; in the present study, we designed a four-week protocol to investigate the short-term effect of WBVT on EMG activities of the leg muscles in a patient with knee OA. The EMG activities of the leg muscles (vastus medialis, vastus lateralis, gastrocnemius, soleus and semitendinosus) have been studied in various positions in order to evaluate the effectiveness of WBVT in improving the leg muscle strength in comparison with CT and placebo groups. Among the parameters used for the EMG analysis of muscle strength the RMS is the best (37, 38), thus analyzing the EMG data during MVIC was based on the RMS in this study. The results of our study indicated that after a short term intervention, there was a significant difference

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Table 4. Comparison of the progression rate (%) of the RMS values of the studied muscles.

Variable	WBVT group (n=12)	Placebo group (n=12)	CT group (n=13)
	progression rate (%)	progression rate (%)	progression rate (%)
Vastus Medialis (Semi squat)	42.71	38.48	4.21
Vastus Medialis (SLR)	33.62	5.73	6.91
Vastus Lateralis (Semi squat)	17.72	12.59	1.1
Vastus Lateralis (SLR)	13.10	7.32	0.99
Gastrocnemius (Semi squat)	27.61	18.1	7.01
Gastrocnemius (SLR)	25.14	16.6	6.71
Gastrocnemius (Knee Flexion)	24.14	17.24	1.14
Gastrocnemius (Ankle Plantarflexion)	34.04	15.06	1.06
Soleus (Semi squat)	48.73	8.64	18.23
Soleus (SLR)	16.72	10.93	2.24
Soleus (Knee Flexion)	52.05	5.08	15.01
Soleus (Ankle Plantarflexion)	19.76	18.66	26.17
Semitendinosus (Semi squat)	16.70	1.1	8.88
Semitendinosus (SLR)	14.39	4.11	1.5
Semitendinosus (Knee Flexion)	67.74	4.37	6.55
Semitendinosus (Ankle Plantarflexion)	60.94	19.60	23/52

among the groups in the RMS values of the semitendinosus muscle in semi-squat and ankle plantar flexion positions and also in the RMS values of the soleus in ankle plantar flexion.

Vastus Medialis and Lateralis EMG activity in semi-squat and SLR positions

Patients with OA of the knee frequently exhibit changes in vastus medialis muscle, such as neurogenic muscular atrophy, muscle fiber degeneration, a defect in the motor unit recruitment, weakness, altered firing rate, loss of function, reduced surface EMG activity and etc (39, 40). The vastus medialis electrical activity was evaluated in semi-squat and SLR in the groups. No significant differences were seen in RMS values of the vastus medialis between pre and post intervention in each group in the study which may be due to the groups' sample sizes. In spite of the lack of significant difference, the progression rate in WBVT group was about 42% in the semi-squat and 33% in the SLR positions which was much better than the other groups. It should be noted that the progression rate is one of the valuable and most important indicators for assessing a patient's recovery during the course of treatment and determining its effectiveness. Thus, it seems WBVT had a greater impact in improving the vastus medialis strength. The findings of several studies have shown increasing of the EMG activity of the muscles of different parts of the body after exposure to the WBVT (17, 34, 41-43). Previous studies have considered various mechanisms for the effectiveness of WBV in increasing the EMG activity of the muscle, mechanisms such as developing neurologic adaptation, post-activation potentiation, muscle tuning, increasing gravitational load, activation of tonic vibration reflex and other reflexive contraction, synchronization of muscle units, muscle hypertrophy, improvement of proprioceptors ,massive stimulation of propriospinal reflex pathways, increasing excitability of corticospinal pathways, increasing the activity of agonists, hormonal changes ,changing in muscle stiffness ,increasing the muscle temperature and other unknown mechanisms which improve muscle function due to exposure to the WBV(18, 20, 22, 23, 26, 32-34, 36, 42, 44-52). The semi-squat position that was used in the study was another mechanism for increasing electrical activity of vastus medialis in the WBVT group as the findings of Roelants et al (34).

The results of the present study were consistent with the findings of Moras et al. who have investigated the effect of different frequencies of WBVT on the EMG RMS rectus femoris, vastus medialis, vastus lateralis and gastrocnemius (49).

Hazell et al. findings showed the muscles' EMG RMS had been improved after receiving WBVT which confirms the results of our study (48).

Since no study has been conducted in the field of the effect of WBVT on EMG activity of muscles in patients with knee OA, It might be stated that WBVT parameters used in this study (Frequency 30 Hz, the range of 3 mm, in semi-squat position during a 4-week period) could be a helpful role in increasing the RMS value of the vastus medialis which represent of improving the muscle strength.

Although there were no significant differences among our groups after the intervention, the progression rate of vastus medialis RMS value in WBVT group was 42.71% while they were 38.48% and 4.21 % in placebo and CT group respectively; it seems that WBVT may be an effective approach as a strengthening modality in the patient with knee OA. The progression rate of vastus medialis RMS value in the placebo group was also impressive despite the lack of exposure to the WBVT. The cause of this finding may be due to two factors: one using the semi-squat position in the placebo group with the same duration as in the WBVT group; and the other the psychological effects of WBVT. According to Arampatzis et al the increasing in knee flexion angle raises the vastus medialis EMG activities (53). This finding is similar to our result in the placebo group. It seems WBVT has not had any placebo effect based on the results of the study and the outcomes other studies (35,48,52). Also, the semi-squat standing in off vibration system should have any impact on the muscle strength. The previous researches indicate that the keeping the squat position would increase the strength of lower extremities' muscles (54-59) .Furthermore, no significant differences

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were shown in the vastus medialis RMS value in SLR position among the groups, but there was a significant rate in progress of the above-mentioned variable in WBVT group (33. 62%) compared two other groups (placebo:5.73% and CT: 6.91%).

Our findings did not reveal any significant difference in the vastus lateralis RMS value in semi-squat position between pre and post intervention and also among the groups, but the vastus lateralis RMS value in SLR position showed a significant difference in the WBVT group which is due to increasing neuromuscular response after vibration training. Our finding was not in the support of the Liao, results that stated the semi-squat position is the position of choice in EMG activity enhancement(22, 43). The results of the present study were consistent with the findings of Machado et al. who did not find any significant difference either in the in the vastus lateralis EMG activity after WBVT in of the same subjects' age and position as our study (52). Perhaps, the small sample size of the groups, the effects of doing exercise at home and keeping semi-squat position in the placebo group was among the reasons for the lack of significant differences among the studied groups.

Gastrocnemius and soleus EMG activity in semi-squat, SLR, knee flexion and ankle plantar flexion positions

The findings confirmed the gastrocnemius EMG activity did not reveal any significant difference in the studied positions between pre and post intervention in all groups. ANOVA, also, did not show any significant difference in the gastrocnemius RMS value among the groups. Similar to our findings, Simorgh et al has not obtained any significant difference in RMS response of gastrocnemius muscle(60).Improper WBV frequency to stimulate the gastrocnemius motor neurons might be one the reasons for the lack of significant differences. It should be noted that although the gastrocnemius is among the first muscles to start squat motion, activation of the other leg muscles plays a major role in keeping semi-squat position(48).The progression rate of gastrocnemius in different positions in the WBVT group was much higher the other groups as same as the progression rate of vastus medialis and lateralis.

The Soleus EMG activity did reveal a significant difference in the semi-squat position between pre and post intervention in WBVT group which can be attributed to the effects of vibration therapy. ANOVA did not show any significant difference in the Soleus RMS value among the groups. The findings of the present study were not similar to the results of Simorgh et al. study in this regard (60). The difference between the results of the Simorgh's and the present study might be due to the different ways in registering soleus EMG signals or tiredness and the inability of subjects to maintain contraction. On the other hand, Simorgh's subjects were young and healthy women while our subjects were middle-aged patients with knee OA (60).

Semitendinosus EMG activity in semi-squat, SLR, knee flexion and ankle plantar flexion positions

Another purpose of the present study was to examine the effect of our intervention on EMG activities of semitendinosus muscle. Our findings confirmed a significant difference the RMS value of semitendinosus in knee flexion position in the WBVT group and also in the ankle plantar flexion in CT group between pre and post intervention. The progression rates of the RMS value of semitendinosus in all studied position in the WBVT group were much greater than the other groups. These results suggest that WBV could activate semitendinosus in different positions and was effective in increasing semitendinosus strength in the WBVT group. Unfortunately, few researchers studied the WBV effects on the EMG activity of hamstrings. Similar to our finding , Karatrantou et al. found that a short-term WBVT resulted in increasing hamstring strength and hamstrings-to-quadriceps ratio (51). The lack of significant differences in semitendinosus EMG activity in semi-squat position in the WBVT group might be the lack of necessity for intense activation of semitendinosus to neutralize anterior shear forces on the proximal tibial in this position. A significant difference was shown in the RMS values of the semitendinosus muscle by the ANOVA; the Tukey-LSD test revealed a significant difference between the placebo and WBVT groups and also a significant difference between the CT and WBVT groups. The cause of the significant difference in the semitendinosus EMG activity in the WBVT group like the other researches which studied the effect of vibration training on muscle's strength might be attributed to the effect of vibration training in increasing muscle's response to mechanical stimulus and increasing strength and power of the muscle through the mechanisms that have already been previously discussed (22, 23, 25, 26, 32, 34-36, 41, 44, 45, 47-52).

The major finding of our study was the improvement in the muscles RMS progression rate which is one of the important indicators in increasing muscle strength in the patients with knee OA during a four-week period of WBVT.

The most beneficial advantage of WBVT is that the patient's muscle strength is improved in a short period of time. Since the patients with knee OA are the elderly who do not have the ability to do exercises, the WBVT is a helpful modality for them to strengthen their weak muscles without doing any physical activities and intense exercises. It is considered the great advantage of the present study. The other strong point of the study is the precise signal processing and electromyographic data analysis in Biometrics software.

There are several limitations in our study. A major limitation of our work was the small sample size of each group. In order to decrease the effect of small sample size in a future study, recruitment of more subjects can be helpful. Furthermore, the muscles strength was not assessed with other evaluating devices like the isokinetic system. Thus further researches are needed, however, to evaluate muscles strength. It is also recommended that the wireless EMG system, if possible, is used for further studies. Finally, long-term follow-up study of patients with knee OA can determine the impact of the vibration training.

Conclusion

The remarkable result of the study was an impressive improvement in the muscles RMS progression rate after a

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four-week WBVT period.

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