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ORIGINAL RESEARCH

The effect of adding whole body vibration training to strengthening training in the treatment of knee osteoarthritis: A randomized clinical trial

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Summary Strengthening training (ST) and whole body vibration training (WBV) alone may improve symptoms of osteoarthritis of the knee. In this study, we investigated the effect of adding WBV training to quadriceps and hamstring muscles strengthening training on functional activity, pain, quality of life and muscle strength in patients with knee osteoarthritis. 28 volunteers were randomly allocated to two groups; 1) quadriceps and hamstring muscles strengthening training (ST group, 13 patients) and 2) quadriceps and hamstring muscles strengthening training along with WBV training (ST + WBV group, 15 patients). The treatment protocol for both groups involved 3 sessions per week for 8 weeks. All measurements were performed before and after intervention. The measurements included: pain by means of a visual analogue scale (VAS), quality of life by means of the WOMAC scale, functional activity by the 2 min walking test (2MWT), time up & go test (TUGT) and 50-foot walking test (50FWT) and the muscle peak torque (MPT), total work (TW) and muscle power (MP) as muscle performance of quadriceps and hamstring muscles by an Isokinetic Biodex machine. After intervention, the comparison of mean changes between two groups showed improvement in the WBV + ST group

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in terms of 2MWT, MPT, TW and MP variables ($P < 0.05$). However, no significant difference was found between the experimental groups in term of pain, quality of life, TUGT and 50FWT. These results suggest that adding whole body vibration training to strengthening training may provide better treatment effects for patients with knee osteoarthritis.

Introduction

Osteoarthritis (OA) is the most common Non-inflammatory degenerative joint disease with an incidence of 60–90 percent in elderly people over 65 years old (Das and Farooqi, 2008). The main symptom of knee OA is pain which is usually caused by weight bearing. Other features of knee OA include apparent osteophytes, difficulty of motion, varus and valgus deformities, joint instability, radiological signs and joint calcification (Altman et al., 1986). Although, there is no curative treatment for knee OA, generally three categories of palliative treatment have been recommended including; surgical treatment, pharmaceutical treatment and non-pharmacologic conservative treatment, such as exercise therapy (Fauci et al., 2008) and whole body vibration (WBV) (Stein et al., 2010).

It has been claimed that strengthening exercises may provide several beneficial effects for people with OA, including; facilitate analgesic endogenous opioids that cause the patient to be more tolerant (Fraioli et al., 1980), reduction in the degree of disability (Minor and Lane, 1996), considerable reduction in weight (Jenkinson et al., 2009) and other mechanical changes in the biomechanics of knee (Thorstensson et al., 2007). In addition, strengthening exercises may cause physical and mental effects that directly affect knee joint (Pearle et al., 2005). Because the excessive and unnatural forces may damage articular cartilage, it is assumed that the beneficial effects of muscle strength in patients with knee OA, may be due to the increased joint stability and reduced joint stress (McQuade and de Oliveira, 2011).

The other way of strengthening muscle force is WBV, which has been widely used recently to improve muscles performance (Stein et al., 2010). Several studies have confirmed that WBV training reduces age-related muscle atrophy and is an effective intervention in improving the functional capacity (Roelants et al., 2004) and metabolism (Rehn et al., 2007). Thus, the effects of WBV training and regular strengthening exercises is similar, except that the joint force is smaller In WBV training (Trans et al., 2009). However, recent research has shown significant improvements of symptoms in patients with osteoarthritis of the knee by this technique (Trans et al., 2009).

While, it has been stated that each of these interventions have beneficial effect for patients with knee OA, there is no study to investigate the beneficiary effects of combinations of these interventions. This study was designed to investigate the effects of adding WBV training to muscle strength exercises of the knee in patients with knee OA.

Method

28 of 58 patients with knee OA, who had been referred by a rheumatologist to Neuromuscular Rehabilitation Research Center, participated in the study according to the inclusion and exclusion criteria. The participants (2 males and 26 females) were randomly allocated into strengthening training (ST) (male = 31%, female = 69%) or strengthening training with WBV training (ST + WBV) (male = 0%, female = 100%) groups, using closed envelopes. Table 1 shows the demographic and the base line data of both experimental groups.

Inclusion criteria included having mild to moderate chronic osteoarthritis of unilaterally or bilaterally tibiofemoral joint according to the method of Kellgren & Lawrance, 35–76 years old, a history of symptoms more than a month and being able to walk with or without assistant devices (Hubley-Kozey et al., 2006). Reporting other diseases such as: diabetes, diseases of musculoskeletal, neuromuscular, cardiovascular, respiratory, etc., the use of injections or other invasive treatments (such as surgery) in the lower extremities during the last three months, having an artificial hip or knee joints, medication, history of trauma to knee joint during last week, performing regular professional exercise and extreme physical weakness were considered as exclusion criteria (Hubley-Kozey et al., 2006). The procedure of study is shown in Figure 1.

After signing the consent form both groups received an educational leaflet (Fransen, 2004), continues ultrasound therapy, hot pack, TENS (Cameron, 2003) and strengthening exercises protocol (Petersen et al., 2011). The treatment was done in each group by a separate physical therapist. Strengthening training protocol was performed 3 times a week for 8 weeks and included flexion and extension exercise of knee joint with the quadriceps chair. Before starting exercise training, all subjects were asked to perform warm up exercise on an ergonomic bicycle for 5 min. Each exercise session included 3 set with 2 min interval and the load of exercise was progressively increased from the 60–65% of 10 RM in the first set, 70–75% of 10 RM in the second set and 80–85% of 10 RM in the third set. The amount of 10 RM was measured every week for each participant. If the subject reported pain during exercise (VAS$>$ 5), the range of motion was reduced. If the pain remained, the load was reduced (Petersen et al., 2011).

WBV training was applied after strengthening exercises in SE + WBV group, using Fitvibe device (Italy) with 2 mm vertical vibration intensity in a static situation. The patient was asked to stand on the vibration platform with bare feet and bent knees so that no fatigue or pain was sensed

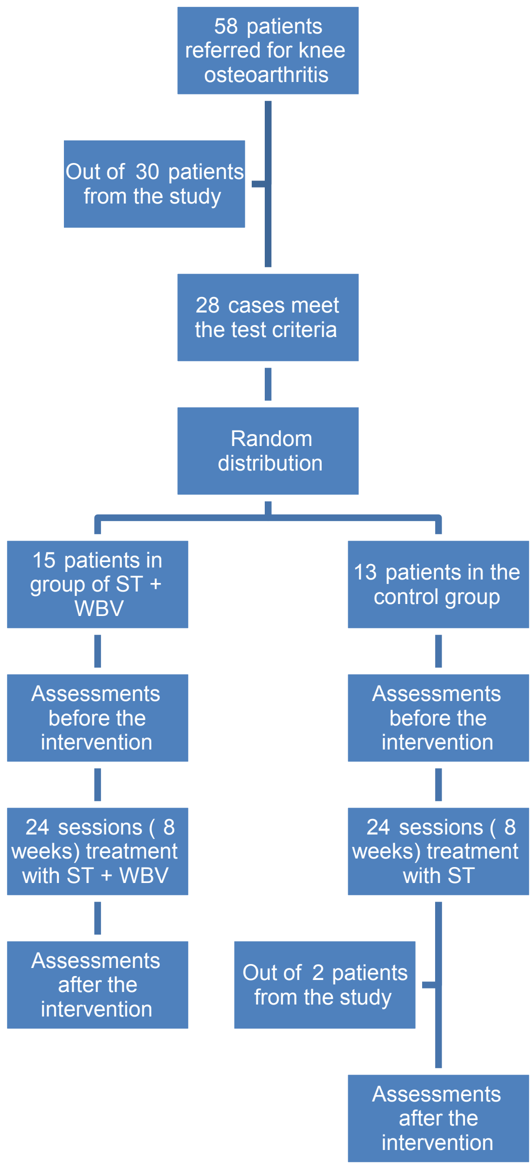

Figure 1 Study procedure, ST: strengthening training, WBV: whole body vibration.

(Cardinale and Bosco, 2003). The protocol of applied vibration is given in Table 2 (Trans et al., 2009).

All measurements were performed by a blind assessor to the groups of study and included the muscles performance evaluation, functional activities, knee pain and the quality of life.

Muscle performance evaluation: The isokinetic concentric quadriceps and hamstring muscle peak torques were measured by Biodex isokinetic system (Model 4Pro) (Lund et al., 2005). The machine was initially calibrated just before the start of each test session. Subjects were positioned sitting with the backrest at an 85° angle and were instructed to grip the sides of the seat during the testing. The thigh, pelvis, and trunk were stabilized with straps. An adjustable lever arm was attached to the subject's leg by a padded cuff just proximal to the medial malleolus. The axis of rotation of the dynamometer arm was adjusted to the lateral femoral epicondyle. Gravity corrections to torque were calculated by the computer software (Dvir, 2004). Conventional concentric continuous isokinetic tests were used. Subjects were familiarized with test procedures by performing 3 consecutive warm-up trials, one of which was a maximal contraction. There was a 2 min break between the warm up and test procedure. During concentric tests, the subjects were asked to push continuously the lever arm of dynamometer up and down through the range of motion between 10° and 90° of knee flexion. All subjects were encouraged verbally to exert maximal effort during the test. The participants performed 5 maximal continuous flexion-extension repetitions for each angular velocity of 90°/sec and 120°/sec in each leg. The order of speed was from slower to faster. A 60 s rest interval was allowed between each contraction speed (Snyder et al., 2011). Then, the machine measured the peak torque, total work and average power of quadriceps and hamstring muscles during knee extension and flexion, respectively. The peak torque, total work and average power for each muscle were calculated from data recorded for both legs during the isometric contraction at both 90°/sec and 120°/sec of angular velocity.

Functional activity tests included; 2 min walk test (2MWT), timed up and go test (TUGT) and timed 50 foot walk test (T50FWT) measurement.

2MWT: To complete 2MWT, individuals were free to use a mobility aid or not, making this measure clinically useful. The 2MWT was recorded indoors in a well-lit 25-m tiled hallway. The score recorded was the total distance travelled during 2 min. Participants were instructed to "walk as quickly and safely as you can for 2 min". All participants practiced walking in the test hallway before measuring began; however, to prevent fatigue, the complete 2MWT was not practiced (Kolen et al., 2012).

TUGT: The patient was in the sitting position on a standard chair and we asked him to rise from the chair and walk straight for 3 m, with maximum effort and then return the same way, and sit on the chair again. The elapsed time during the test was measured with a standard chronometer (Adegoke et al., 2012).

50FWT: The time required to walk 50 feet was measured to evaluate the functional activity of the patients. The reliability of this test has previously been confirmed. The test was repeated 3 times with 5 min rest intervals to prevent fatigue. The time required to complete the test was measured using a standard chronometer and the lowest time was considered (Huang et al., 2011).

Measurement of knee pain: Knee pain perception was measured by means of a visual analogue scale (VAS), on which the patients could indicate their assessment of pain perception along a 10 cm line ranging from 0 (no pain at all)

Table 1 The mean (SD) of demographic variables in the whole body vibration plus strengthening training (ST + WBV) and strengthening training (ST) groups.

Variable	ST + WBV n = 15	ST n = 13	P value
Age (year)	51.8 (8.3)	54.0 (3.9)	0.959
Weight (kg)	75.3 (8.7)	72.1 (8.5)	0.273

Table 2 Whole body vibration training protocol.

Week of vibration intervention	Hold time	Rest time	Frequency	Number of set
1	30 s	30 s	25 Hz	6
2	40 s	40 s	25 Hz	6
3	50 s	50 s	25 Hz	6
4	60 s	60 s	25 Hz	7
5	50 s	50 s	30 Hz	7
6	50 s	50 s	30 Hz	8
7	60 s	60 s	30 Hz	8
8	70 s	70 s	30 Hz	9

to 10 (the most severe pain that I can imagine) (Adams et al., 1995).

The quality of life evaluation: The short type of WOMAC scale was used to assess the quality of life. The scale consisted of 8 items which determined treatment's the patient's own assessment of his physical performance. Each question was assigned from zero (no problem) to 4 (severe problem). Higher scores indicate poorer performance (Bilbao et al., 2011).

Statistical analysis

After collecting data, the Kolmogorov Smirnov test was used to assess the normality of the data. In order to evaluate the effect of an intervention in each group, paired t-test was used to compare before and after means. To compare the mean change of variables between the two groups, independent t-test applied to the data at significance level of 0.05 and 95% confidence interval was used.

Results

28 patients with knee osteoarthritis participated and completed the study, except two patients in the control group, who withdrew due to the lack of time to fulfil the training program.

Table 3 shows base line data of both experimental groups. The two groups were matched for demographic and basic data of variables. There was no significant difference between groups in term of demographic and base line data.

By comparing the mean changes after the intervention between two groups, it was found that addition of WBV training to the strengthening training can significantly improve peak torque (p = 0.002, 95% CI 5.25 to 21.03), total work (p = 0.033, 95% CI 0.55 to 19.87), muscle power (p = 0.044, 95% CI 0.89 to 18.97) of quadriceps muscle compared to the control group. The results showed that the combination of WBV and strengthening exercise was significantly more effective in improving functional activity tests (the mean percent change of 2MWT, 50FWT and TUGT) than the strengthening exercise alone (p = 0.009, CI 0.22 to 14.66). However, the mean changes of hamstring muscle performance, pain perception, WOMAC scale, TUGT and 50FWT were not significantly different between the two groups (Table 4).

Table 3 The mean (SD) of baseline variables in the experimental and control groups.

Variable	ST + WBV n = 15	ST n = 13	P value
VAS	7.7 (2.3)	7.0 (2.4)	0.760
WOMAC	16.3 (4.9)	16.8 (2.3)	0.799
2MWT (m)	117.1 (17.5)	130.5 (22.3)	0.198
50FWT (s)	14.1 (2.6)	13.0 (1.7)	0.507
TUGT (s)	11.2 (2.4)	12.0 (4.4)	1.000
PTQ (Nm)	39.7 (14.1)	53.8(20.4)	0.087
TWQ (J)	106.5 (46.9)	126.0(49.0)	0.443
MPQ (w)	33.4 (14.3)	37.6 (16.2)	0.574
PTH (Nm)	19.1 (10/2)	19.4 (10.6)	1.000
TWH (J)	39.7 (30.3)	30.6 (16.1)	0.760
MPH (w)	11.0 (7.1)	8.7 (4.8)	0.507

SD = standard deviation, ST = strength training, ST + WBV = strength training with whole body vibration, 2MWT = 2 min walking test, 50FWT = 50 foot walking test, TUGT = time up and go test, PTQ = peak torque quadriceps muscle, TWQ = total work quadriceps muscle, MPQ = muscle power quadriceps muscle, PTH = peak torque hamstring muscle, TWH = total work hamstring muscle, MPH = muscle power hamstring muscle.

Discussion

OA of knee is the most common non-inflammatory degenerative lesion (Das and Farooqi, 2008). Despite the lack of definitive treatment of this lesion, exercise therapy is used as one of the most important therapies for this purpose (Fauci et al., 2008). Muscle strengthening exercise is a key component of most treatment regimens (Hochberg et al., 1995). WBV training (Trans et al., 2009) and strength training are two common methods that can effectively improve muscle strength (Minor and Lane, 1996). This has

Table 4 The mean changes (SD) after intervention in ST + WBV training and ST groups.

Variable	ST + WBV n = 15	ST n = 11	P value
VAS	4.1 (2.9)	2.6 (3.0)	0.218
WOMAC	9.7 (4.4)	8.9 (5.8)	0.673
**FATS	*13.1 (8.2)	*4.6 (6.5)	0.009
PTQ (Nm)	*9.2 (8.2)	*-3.9 (10.3)	0.002
TWQ (J)	*38.9 (9.9)	*10.3 (8.8)	0.042
MPQ (w)	*11.5 (12.8)	*1.6 (9.5)	0.033
PTH (Nm)	5.0 (9.7)	1.5 (5.7)	0.264
TWH (J)	23.0 (39.0)	17.9 (18.3)	0.662
MPH (w)	4.3 (9.2)	4.1 (6.4)	0.954

*Significant difference.
**the mean percent change of 2 min walking test, 50 foot walking test and time up and go test.
SD = standard deviation, ST = strength training, ST + WBV = strength training with whole body vibration, FATS = functional activity tests, PTQ = peak torque quadriceps muscle, TWQ = total work quadriceps muscle, MPQ = muscle power quadriceps muscle, PTH = peak torque hamstring muscle, TWH = total work hamstring muscle, MPH = muscle power hamstring muscle.

been shown in previous studies of treatment of knee OA (Jenkinson et al., 2009; Trans et al., 2009). However no combination of these therapeutic methods has been applied for the treatment of knee OA yet. In this study we attempted to fill this research gap.

Quadriceps muscle performance: The results showed that the mean change of peak torque, total work and muscle power of quadriceps muscle is significantly greater in the combination therapy group compared to the control group. Vibration has attracted the attention of researchers as a specific method of strengthening the muscles, for two decades (Mester et al., 2006). There are a few theories about how the effects of vibration on muscle performance have been considered. However, the initial increase in power generation capacity is often attributed to neural factors (Mester et al., 2006). It is probably related to increased sensitivity of the stretch reflex that causes muscle contractions. This mechanism is called the Tonic Vibration Reflex (TVR) (Mester et al., 2006). WBV mechanism is still under investigation; however, it is proposed that it will enable the mono-synaptic reflex in the muscles by creating a stretch-shortening cycle. Consequently, the EMG activity increases during WBV, because it has provoked muscular activity (Cochrane et al., 2008). Therefore, it is an important technique for muscle re-education (Lapole and Perot, 2010). However, there is a dearth of information in the literature regarding the physiological modulation following WBV on living systems and tissues and the most appropriate frequency, duration and intensity of vibration have not been identified yet. Furthermore, most of the studies do not report the characteristics of vibration waves (Prisby et al., 2008).

WBV has a characteristic that can cause changes in gravitational acceleration as well as strengthening training, and thereby improve muscle performance (Bosco et al., 1999b). In other words WBV affect the neuromuscular system and hormones, thereby increasing gravity load (Kvorning et al., 2006). Interestingly WBV training takes effect in less time than resistance training (Bosco et al., 1999a). For example, effect imposing a 10-min WBV, is equivalent to doing 150 exercises leg press or half squat, with a force three times of the body weight, 2 times a week for 5 weeks (Bosco et al., 1999b). The result of the present study is consistent with the results of Johnson, von - Stengel and Stein studies (Johnson et al., 2010; Stein et al., 2010; von Stengel et al., 2012). But it is inconsistent with the results of the works of de Ruiter (de Ruiter et al., 2003), and Segal (Segal et al., 2013), which is probably because these researchers used the normal population. The de Ruiter's study measured isometric strength of quadriceps muscle, but considering most of isotonic contraction in activities of daily living we chose this model for training and testing (Dvir, 2004). This is another possible reason for the inconsistent results.

Hamstring muscle performance: The results of this study showed that the addition of WBV training on strengthening training did not have any significant impact on hamstring muscle performance indices (peak torque, total work, muscle power) compared to control group, in patients with OA. The mechanism of the effect of WBV training on muscle performance indicators in the discussion of the quadriceps muscle was expressed. According to the discussion about the quadriceps performance changes, we should see similar results in the hamstrings. However it should be noted that the effects of WBV training on muscle depends on three main factors; frequency of vibratory stimulations, the extent of activation of motor units and the initial length of the muscle architecture (Bosco et al., 1999b). The initial length of the muscle is one of the key factors determining the effectiveness of training. Studies have shown that muscles at stretch, are more sensitive to vibrational excitation, and are more contract more rapidly. This hypothesis states that the greater the length of the muscle, the more muscle tension there will be, thus producing a greater response to vibration (Macintyre and Kazemi, 2008). Rohemert and colleagues stated that stretched muscles, are probably more sensitive to vibrations (Rohmert et al., 1989). Because the vibration is more effective in stretched muscle, the squat is the optimum condition for vibrational excitation of the quadriceps muscle (Cardinale and Lim, 2003), but not for the hamstring muscles (Feland et al., 2010). Though it seems, the difference in stretch is only in the single joint muscles, because two joint muscles are stretched roughly to the same degree by a normal free standing squat, in this study, we used the squat position to apply WBV. This could be an explanation for the lack of impact of the intervention on the hamstring, however these results are not supported by Claerbout's results (Claerbout et al., 2012). The main reason for this paradox is that Claerbout's study was done on MS patients who had a neurological disease, while we have studied patients with a musculoskeletal disorder (Fauci et al., 2008).

Functional activity tests: The results showed that the percent of mean change of functional activity tests (2MWT, 50FWT and TUGT) is significantly higher in the combination therapy group compared to the control group. Current knowledge is not extensive enough about physiology and neurological mechanisms of WBV training. But some reasons have been suggested to explain this effect, such as; increased facilitation of central and peripheral nervous systems, coordination, stimulation and retrieval of more motor units, threshold reduction of Golgi tendon organs, preventing antagonist muscle activity increases, and changes in hormones, changes in the concentration of neurotransmitters (dopamine and serotonin) and activation of gamma motor units and muscle spindle (White, 2001).

There are some studies that may confirm our findings (Avelar et al., 2011; Salmon et al., 2012), while some other results are inconsistent. The reason of inconsistency may be the type of patients treated who had neurological disease (Brogardh et al., 2010). On the other hand, the three-week period for Claerbout study was a short time to obtain the desired results (Claerbout et al., 2012).

VAS & WOMAC: The results of this study showed that the addition of WBV training to strengthening training had no significant impact on VAS and WOMAC scores in comparison to the control group in patients with OA. Various studies showed that WBV has a similar effect with regular strengthening training protocols, while less force will be loaded on the joint (Stein et al., 2010). The beneficial effects of strengthening training are divided into several major factors for people with OA including a facilitation of internal opiates that cause the patient to be more tolerant (Fraioli et al., 1980), reduction of the degree of disability

(Minor and Lane, 1996), a significant decrease in weight (Jenkinson et al., 2009), other mechanical changes on the biomechanics of knee (Thorstensson et al., 2007), mental impacts associated with the strengthening (Pearle et al., 2005), joint stability and reduced joint stress (McQuade and de Oliveira, 2011). Since the strengthening exercise was used alone in the control group, it appears that exercise alone is enough to improve the VAS and WOMAC scores. These results may be confirmed by the Trans's study (Trans et al., 2009), while these are against Avelar's findings (Avelar et al., 2011). Unlike the present study, Avelar used closed chain exercises with longer treatment periods. Both of these differences may be due to inconsistent results of studies (Avelar et al., 2011).

As a whole, we should bear in mind that the differences in the observed effects between different studies could be due to their protocol features, such as methods of practice, the vibration parameters (frequency, duration and intensity), muscle characteristics (Cochrane et al., 2008), as well as the type of pathological condition involved (Trans et al., 2009).

In the cases described, the vibration parameters may have a major impact on the physiological effects, although, the ideal dose of vibration has not been specified so far. The best vibration parameter to attain the highest positive impact of WBV has not been identified yet (Mester et al., 2006). Vibration training consists of three components: frequency, duration and intensity which can be adjusted independently for each. Therefore various protocols that employ various combinations of these three components, makes it difficult to compare the results. In conclusion it may assume that different vibration programs have led to different results.

Although several potential risks and benefits of WBV training has been reported, but its exact mechanism of action is not yet known. Technical differences in the application of WBV and clinical findings may be due to the lack of knowledge about the physiological basis of the work. In other words, it is not completely known whether vibration exerts its effect on muscle or induces systemic responses in the central nervous system (Casale et al., 2009). More studies are needed to find the ideal combination of vibration parameters, to obtain best and functional result.

Conclusion

Our results showed that the adding of WBV training to the strengthening training protocol in patients with osteoarthritis of the knee is able to significantly increase quadriceps muscle performance indices and functional activities. But this method is not able to improve other variables measured. Considering therapeutic effect and the cost of this treatment, its clinical application could be negotiable.

It should be noted that participation of some of the patients in sports activities such as walking, are limited to checking the net effects of treatment. The relatively long time of treatment (8 weeks) increases the possibility of unanticipated events in patient's personal lives.

Future studies are recommended for designing a clinical trial and systematic review to determine the best frequency, duration and intensity of WBV. Other research can be conducted with a longer treatment period and larger sample size, to investigate the effect WBV training on the other side-effects of knee osteoarthritis.

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