Whole-body vibration versus Tai Chi exercise for controlling balance in lower-limb ulcers: a pilot, randomized, controlled trial

Eman M. Othman, Asmaa F. El-Sayed, Heba M. Mohamady

Department of Surgery, Faculty of Physical Therapy, Cairo University, Cairo, Egypt

Correspondence to Eman M. Othman, PhD, 3, El Said Hussin Street, Kholosy, Shoubra, Cairo, Egypt Tel: +20 100 125 6706; e-mail: dr.emanothman@yahoo.com

Received 16 February 2017
Accepted 28 March 2017

Bulletin of Faculty of Physical Therapy 2018, 23:43–52

Background
Foot and leg ulcers are serious complications to both patients and healthcare systems, which may contribute to impaired balance and increased risk of falling.
Purpose
This study was designed to determine which approach is more effective in improving balance in lower-limb ulcers cases – whole-body vibration or Tai Chi exercise.
Patients and methods
Thirty (12 females and 18 males) patients with foot ulcers were randomly assigned into two equal groups of 15 individuals. Both groups received their routine medical and physical therapy. In addition, group A received whole-body vibration at a frequency of 25–30 Hz and amplitude of 3–5 mm, 30 min/session, three times/week for 6 weeks, whereas group B received 6 weeks of Tai Chi exercise [In Balance (IB) program] for 15–45 min, three times/week for 6 weeks. The overall stability index was measured using a Biodex balance system at two time intervals – before treatment and 6 weeks after treatment.
Results
Both whole-body vibration (1.7±0.51) and Tai Chi exercise (2.53±0.48) groups showed significant improvement in stability index values 6 weeks after treatment with better improvement in the whole-body vibration group (P=0.0001).
Conclusion
Both Tai Chi exercise and whole-body vibration therapy have positive effects on balance in patients with foot ulcers. However, whole-body vibration therapy is more effective.

Keywords:
Biodex stability system, dynamic balance, Tai Chi exercise, ulcer, whole-body vibration

Bulletin of Faculty of Physical Therapy 23:43–52

1110-6611

Introduction

Chronic wounds are not typically seen as a pressing healthcare problem; however, lower-limb ulcers comprise a common, complex, and costly condition [1]. A systematic review by Graham *et al.* [1] revealed that the occurrence of lower-limb ulcer increases with age. Chronic lower-limb ulcers are a significant burden to both patients and healthcare systems [2,3]. Foot and leg ulcers are serious complications because they often precede lower-limb amputation [4,5]. Previous studies have demonstrated that lower-limb ulcers can cause one or more of the following factors that affect balance: loss of mechanoreceptors in the sole of the foot, loss of proprioception in the lower limb, decreased balance confidence, and fatigue of lower-limb muscles. Furthermore, lower-limb ulcers can result from peripheral neuropathy, especially diabetic peripheral neuropathy (DPN), which is considered as one of the main causes of balance disorders; therefore, patients with lower-limb ulcers definitely have defective balance [6–11]. Peripheral neuropathy is usually profound before loss of protective sensation; the consequent vulnerability to physical and thermal trauma increases the risk of foot ulceration seven-fold [12]. The loss of sensation associated with DPN is thought to contribute to impaired balance, altered gait patterns, and increased risk of falling. People with DPN exhibit greater postural sway when standing, and numerous gait studies have revealed characteristic changes in walking patterns associated with DPN, including decreased muscle power generation at the ankle, decreased knee joint flexion, and decreased ground reaction forces [13].

Postural control is the maintenance of upright posture, and typically involves the use of most of the body's major muscle groups – the visual and vestibular systems and sometimes the auditory system. Postural control is essentially a matter of achieving postural stability [14]. Postural sway typically consists of small-amplitude motion; it can be a threat to balance, and thus

 DOI: 10.4103/bfpt.bfpt_21_16

becomes a challenge for the control of posture. Studying dynamic postural control adds additional demands of proprioception, range of motion, and strength while attempting to maintain an upright and steady posture [6]. The control of balance, both under static or dynamic conditions, is considered as an important need for physical and daily activities [15]. Postural control variables have often been used to evaluate patients with various musculoskeletal or neuromuscular disorders [16]. The Biodex balance system (BBS) has been used to evaluate postural balance in recent years. The BBS has high reliability in assessing dynamic postural balance [17,18].

Exercise that improves lower extremity balance and strength (force-generating capacity) has been shown to be effective in reducing falls in older adults [19–22]. There is evidence suggesting that daily weight-bearing activity may decrease the risk of foot ulceration [23,24]. Intense exercise regimen designed to improve distal lower extremity strength was well tolerated and improved three clinical parameters of balance in a group of older persons with peripheral neuropathy. It is not known whether an exercise regimen will improve the balance impairments identified in older persons with peripheral neuropathy, which is the main cause of plantar ulcers [25]. Previous studies have examined the effect of Tai Chi training on balance. They found that after training there is an increase in time to first fall, maintenance of balance improvements acquired by other balance training, and improvement on standing measures of balance [26,27].

Mechanical vibration had aroused great interest because it had been hypothesized that a low-amplitude, high-frequency stimulation of the whole body might positively influence many risk factors of falling and related fractures by instantly improving muscle strength, body balance, and mechanical competence of bones [28–31]. Previous studies have shown that whole-body vibration (WBV) is associated with increases in lower limb muscle strength [30–36], which is essential for postural stability.

Problematically, the authors were unable to identify studies that have addressed the best rehabilitation approach recommended for the treatment of postural sway in lower-limb ulcer cases. Accordingly, the main hypothesis of the present study was that WBV and Tai Chi exercise approaches would result in improvement in stability index (SI) outcomes. We also sought to determine which approach is more effective in improving balance in lower-limb ulcer cases – WBV or Tai Chi exercise.

Patients and methods

A prospective, randomized, parallel group, active, controlled study with a 1 : 1 allocation ratio was conducted from April 2014 to July 2015 at a research laboratory of the Faculty of Physical Therapy, Cairo University. Patients of both sexes (12 females and 18 males) with chronic unhealed unilateral lower-limb ulcers grade II and grade III according to the Wagner–Meggitt classification [37] (located on the sole of the feet) associated with postural sway symptoms were recruited from Kasr El-Aini Hospital, Cairo University. All patients signed an informed consent form before data collection. Recruitment began after approval was obtained from our local ethics committee at the Faculty of Physical Therapy, Cairo University. Patients were chosen on the basis of the following criteria: age range 40–60 years, weight range 60–90 kg, and height 150–170 cm. All patients had to be capable of understanding and following the instructions. Patients were clinically and medically stable and free from any medical problem that may affect the outcomes. The physical activity level at baseline was considered to be low in all participants, because none of them had been engaged in any sporting activities. Exclusion criteria included the following: any neurological (except for diabetic peripheral neuropathy) or musculoskeletal disorders that cause disturbance in balance or any contraindications to vibration exposure (i.e. hemiparesis, myelopathy, cerebellar ataxia, vertigo, and so on). Moreover, patients who had cardiac abnormalities or cardiac pacemakers, patient with congenital musculoskeletal deformities, especially in the foot (i.e. pes cavus, hallux valgus, etc.), and patients with visual or auditory impairment were excluded. After an extensive medical screening where a physician checked all inclusion and exclusion criteria, eligible participants were randomly assigned using a balanced assignment protocol to group A – that is, the WBV group (n=15) that received WBV at a frequency of 25–30 Hz and amplitude of 3–5 mm for 30 min/session, three times/week for a total period of 6 weeks – and group B – that is, the Tai Chi exercise group (n=15) that received 6 weeks of Tai Chi exercise (IB program) for 15–45 min three times/week for a total period of 6 weeks. The groups were balanced for eligibility by simple randomization with a generated sequence of letters (from a table of correlatively ordered permutations) for each category and combination of categories. The sequences assigned to patients were placed in envelopes containing information about allocation to each study group. An independent person who was blinded to the research protocol and not otherwise involved in the trial carried out random assignment.

Procedure

Before beginning the study, personal data were collected from all patients. In addition, they were asked about any history of previous lower-limb surgeries and injuries (past history). Detailed analyses of the present ulcers were carried out (present history) by a physician. Medical history including drugs in actual use, especially antidiabetic drugs, was considered. Physical examination included general examination and local examination of the lower limbs, which was carried by surgical staff. Routine laboratory investigations, mainly determination of fasting and postprandial blood glucose levels, were carried out.

Patients of both groups completed 6 weeks of treatment consisting of WBV therapy or Tai Chi exercise program in addition to traditional physical therapy program for lower-limb ulcers, such as active exercise, stretching, endurance, and wound-healing modalities.

Whole-body vibration procedure

Therapists asked the patients before beginning the WBV exercise to warm up by walking for 3 min on a treadmill. Vibration loading was carried out in a standing position on a WBV platform (Power Plate International, Irvine, California, USA) with the knees bent, maintained at a 45° angle, and the back and head straight. The rocking platform with a sagittal axis alternately thrusts the right and left legs upward and downward, thereby promoting lengthening of the extensor muscles of the lower extremities. The reaction of the neuromuscular system is a chain of rapid muscle contractions. This type of training provides reflex muscle stimulation with no serious adverse events. The WBV was applied at a frequency of 25–30 Hz and amplitude of 3–5 mm with a total duration of 30 min/session, three sessions/week for total period of 6 weeks. The whole-body vibration training (WBVT) protocol is shown in Table 1.

Table 1 The whole-body vibration training program

	Repetitions	WBV (s)	Rest (s)	Amplitude (mm)	Frequency (Hz)
Week 1	6	30	30	3	25
Week 2	6	30	30	3	25
Week 3	7	40	40	4	30
Week 4	7	40	40	4	30
Week 5	7	50	50	5	30
Week 6	8	60	60	5	30

WBV, whole-body vibration.

Tai Chi exercise therapy protocol (IB)

In this study, the therapeutic exercise used was Tai Chi with seven elements: relaxation exercises, stretch and relax exercises, pelvis exercises, foot and ankle exercises, leg strengthening exercises, balance exercises, and functional exercises. The Balance (IB) program, derived from principles of Tai Chi, included the seven therapeutic elements of Tai Chi that have been identified as most beneficial for elderly persons. At the beginning of the program, attention was paid to somatosensory feedback signals coming from ankle and hip motions that can be used as input for balance control. Combined with exercises increasing ankle range of motion, proprioception, and sensation can be improved, and co-contractions that are often present to compensate for diminished sensory input may be removed. Later in the program, Tai Chi forms were introduced with the emphasis on slow and continuous motions, trunk rotation, and weight shifting. The exercises were tailored to individual abilities of the participants, in that participants were allowed to perform some exercises in a sitting instead of a standing position because of fatigue or poor balance control. The exercise interventions performed day after day on a firm surface for 6 weeks included the following:

Relaxation exercises

Relaxation exercises included swinging both arms forward and backward while standing with feet placed side-by-side. The same was repeated with one foot placed ahead and the other placed behind, taking care of weight transfer. Patients were then asked to stand with their feet apart more than shoulder width, lower their body, and swing both arms to the left and right in front of the body, while the body is initiating the arm swing. Next, patients were asked to stand with their feet almost closed together, swinging one arm forward and the other one backward simultaneously. The focus was on the pelvis, which shows a horizontal swing from the left to the right, causing trunk rotation and a loose arm swing.

Stretch and relax exercises

Patients were asked to swing both arms slowly in a forward and upward direction with one foot placed in front. Body weight is gradually transferred to the leg in front (stretching phase). When the arms are brought down, the leg placed behind is slightly bent and body weight is transferred to this leg (relaxing phase). Next, while standing, one arm is lifted obliquely sideways and upward, producing a stretch on the same trunk side while inhaling. The arm is lowered slowly, and the same is repeated for the other side, with one foot in front of the other. By shifting weight to the front leg,

both arms are slowly spread out to the side while inhaling, causing an expanding effect on the chest. This position is held for 2 s, and then slowly the weight is shifted by lowering the arms while exhaling. The rear leg is slightly bent.

Pelvis exercises

These exercises are performed by forward and backward rotation of the pelvis while sitting, without leaning against the back of the chair. The focus is on the activating impulse from the buttocks, more specifically the tuber ischiadicum. This is carried out by lifting the left and right buttock alternatively while sitting and pushing the buttock into the chair; making clockwise and counterclockwise circles on the ischia by pelvic rotation; walking back and forth on the buttocks while sitting by lifting the left and right buttock alternatively; and forward and backward rotation of the pelvis while standing with the knees slightly bent, emphasizing a relaxed execution.

Foot and ankle exercises, sitting on a chair

These exercises were performed by moving the toes, which includes spreading out and grasping, first with each foot separately and later with both feet simultaneously; making circles with the forefoot by ankle rotation, while keeping the heel on the floor (five repetitions to the left and five to the right); pronation and supination of both feet simultaneously while sitting and standing holding a chair (five repetitions to both sides); circling with the foot by placing the heel on the floor, then go further to the outside of the foot touching the floor, then the toes, lifting the heel and at the end the inside of the foot touching the floor. Make a circle-like movement is repeated five times, and then the same with the other foot, both feet simultaneously, and in the standing position with support of a chair.

Leg strengthening

These exercises were carried out by pushing the heel firmly on the ground while sitting and holding this position for 6–9 s, and then relaxing (eight repetitions for both legs separately). Front knee strengthening was carried out while sitting in a chair and lifting the leg straight for 8 s (eight repetitions). Knee bending was performed while standing with the feet shoulder width apart (eight repetitions). Leaning the body weight in one foot with the knees bending and simultaneously stretching out the other leg to the front of the body with the heel touching the floor. Then stand with both feet more than shoulder width apart and then bending the knees and lowering the trunk and coming back up (five repetitions).

Balance exercises

Balance exercises were performed by rubbing the legs and ankles firmly with hands; by walking over bags filled with beans, pasta, or chestnuts; by standing with the feet shoulder width apart and trying to relax the back, supported with relaxed breathing; by lumbar back relaxation, that is, slightly lowering the os coccyges and 'reaching' to the floor; by standing with the feet shoulder width apart and making a slow and easy swinging movement shifting body weight to the left and right limb alternatively – the movement starts with lowering the weight slightly to one leg while relaxing and exhaling, and then shifting the weight to the other leg and standing up; by relaxing the lumbar back; and by walking in slow motion, concentrating on shifting body weight, relaxation, inner feeling of safety, and foot placement.

Functional exercises

Functional exercises were carried out by standing up from a chair, emphasizing ground support; standing up from a bed; standing up from the floor, with support of a chair and in different ways; and by walking focusing on erectness and lightness of the body, positioning of the head, and the use of relaxed knees in forward motion.

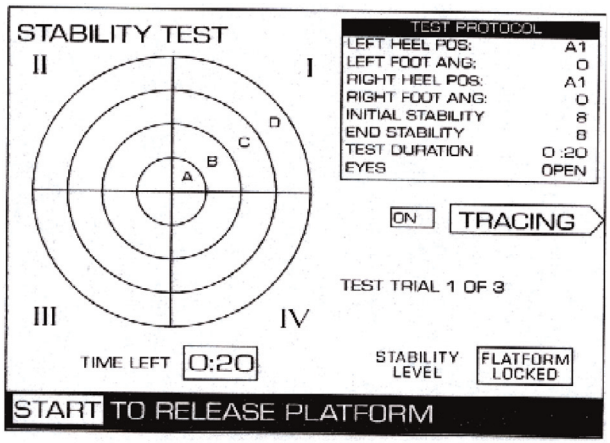
Outcome measures

Both groups underwent identical tests twice with the BBS (Biodex Medical Systems Inc., Shirley, New York, USA) at the balance unit of the Faculty of Physical Therapy, Cairo University: baseline (before treatment) and after 6 weeks of treatment (post-treatment). This system provides a numerical SI that reflects body sway variation around the body's center of gravity; thus, lower the index, the higher the level of stability [38], which is the primary outcome of this study. The SI demonstrated the patient's ability to control the platform angle of tilt – that is, it indicated the amount of platform motion. A high SI (i.e. 5.93) was indicative of a lot of movement, and therefore less stability. On the contrary, a lower SI (i.e. 0.66) indicated a better balance score [39].

The BBS helps test and improve patients' balance through the use of a computerized 'wobble board'. Patients must use their feet and ankles to control the on-screen cursor while the wobble board becomes unsteady (Fig. 1) [40]. The computer analyzes the patient's movements and determines in which direction the patient is reluctant to move or is having difficulty moving. These directional weaknesses may be due to limited range of motion, muscle weakness, or vestibular dysfunction. The degree of

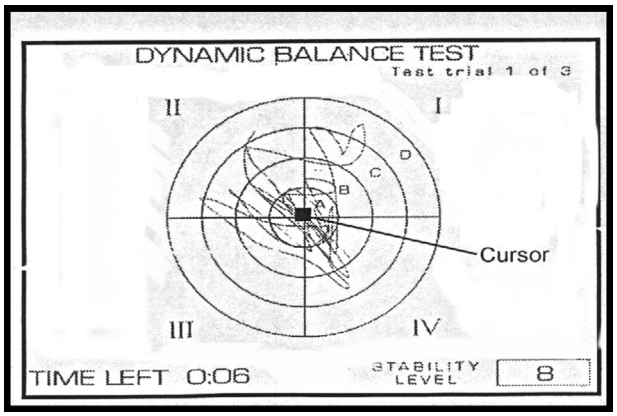
surface instability is controlled by a microprocessor-based actuator (Fig. 2) [40]. The test consists of recording the patient's ability to control the platform variation from a perfectly balanced position. A large variation is indicative of poor control and balance. All patients were given an explanatory session before the evaluation procedure based on the protocols set in the Biodex system operation manuals to be aware about the different test steps of the Biodex system. Patients took the balance test bare feet, with one foot dressed and the other not dressed. Each patient was asked to stand on the center of the locked platform bare footed with the affected leg dressed and the other undressed. All patients were tested on stability level 8 (most stable platform) initially, and at the end all patients were tested for 30 s. The patients were instructed to try to achieve a centered position on the platform (once the platform was set to motion) (Fig. 2) [40]. This was accomplished by shifting the position of their feet to a position that is easy to keep the cursor on the visual feedback screen at the center of the screen grid (Fig. 3). After centering the cursor, the platform was kept elevated beneath the patient's feet while the patient is standing in a comfortable upright position. This followed by recording feet angle and heel coordinates from the platform. The platform *X* coordinate was marked in numbers, whereas the platform *Y* coordinate was marked in letters; the platform was also marked in degree angles from 0 to 45°. The patient's heel coordinates were measured from the center of the back of the heel, whereas foot angle was determined by finding a parallel line on the platform to the center line of the foot. After introducing feet angles and heel coordinates into the Biodex system, the test was initiated and the system started recording sway values (Fig. 2) [40]. The recording screen was divided into four quadrants and four circular zones, so that deviations from the initial centered position were recorded together with direction and extent. The results are expressed as percentage of total test time the participant spent on each zone and quadrant, from which the device calculated an overall balance and mediolateral and anteroposterior indexes. On the basis of these results, patients were categorized into four levels of stability according to the percentage of time each patient spent in each of the zones A, B, C, and D, respectively, where A is the most stable and D is the least stable level. The aim of the centering process was to position the center of gravity over the point of the vertical group reaction force (Fig. 1) [40]. The patient was then instructed to achieve a centered position on the platform by shifting his or her feet position until it was easy to keep the cursor (which represents the center

Figure 1



The bull's eye on which the patient focuses the cursor. Quoted from the operation manual of the Biodex system [40]

Figure 2



The dynamic balance test screen during testing. Quoted from the operation manual of Biodex system [40]

Figure 3

The patient performs the balance test while standing on the center of the platform with two-leg stance

of the platform) centered on the screen grid while standing in a comfortable, upright position without grasping hand rails (Fig. 3). Once centering was achieved and the cursor was at the center of the display target, instructions were given to the patients to maintain the feet position until stabilizing the platform. Each patient's feet position coordinates on the platform were recorded after the first stability measurement, and the same coordinates were used throughout the study to obtain consistency between the tests. At the end of each test trial, a printout report was obtained. The mean value of SIs was used as the test score (Fig. 1) [40].

Sample size determination

Sample size was determined on the basis of a study by Julious [41], who suggested a minimum sample size of 12 patients per treatment arm for a pilot randomized trial. To account for the presence of possible dropouts (20%), the sample size was increased to 15 patients per group.

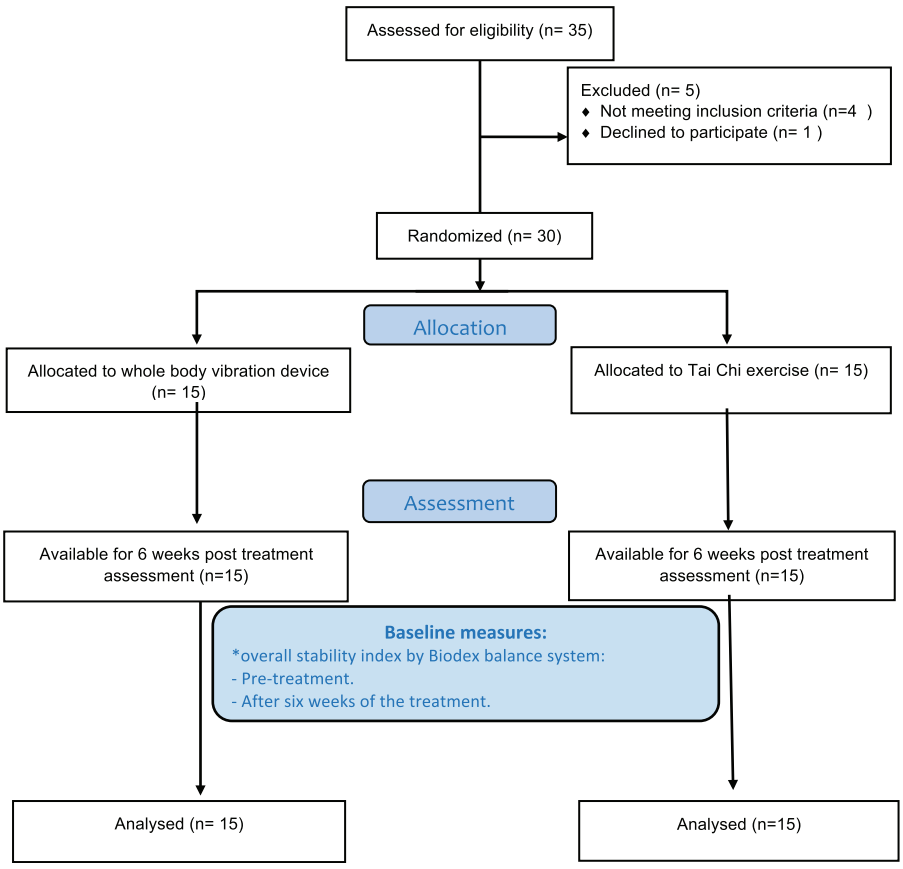
Data analysis

All statistical measures were carried out using the statistical package for the social sciences version 19 for Windows (IBM Corp, Armonk, New York, USA). In this study, the mean±SD were calculated for all patients (two groups of the study). Descriptive statistics and a *t*-test were used for comparing mean demographic data between both groups. Comparisons were made by an independent *t*-test between the WBV and the Tai Chi exercise groups regarding parametric data (age, weight and height) and stability indices. Paired *t*-test was used to compare values before and after treatment in the same group (within group). A value of *P* less than 0.05 was considered statistically significant.

Results

A diagram of patients' retention and randomization throughout the study is shown in Fig. 4. A total of 35 patients were initially screened. After the screening process, 30 patients were found eligible to participate in the study. In total, 30 (100%) completed the first assessment (pretreatment), and 30 patients completed the entire study (6 weeks of treatment). The demographic characteristics of our patients are shown in Table 2. The results are summarized and presented as the mean±SD in Tables 3–5. Both WBV (1.7±0.51)

Figure 4



Flow of study participants

and Tai Chi exercise (2.53±0.48) groups showed improvement in SI values after 6 weeks of treatment, which was in favor of the WBV group (P=0.0001).

Demographic and clinical characteristics of patients

As shown in Table 2, comparison of mean values of age, height, and weight of both groups (A and B) indicated that there is no significant difference in both groups (P>0.05). 47% from the total number of group A and eight male with reported percentage of 53% from the total number of group A. The gender distribution of group B revealed that there were five female with reported percentage of 33% from the total number of group B and 10 male with reported percentage of 67% from the total number of group B.

Stability indexes

Results of stability indexes for the whole-body vibration group (group A)

As shown in Table 3, there was a significant decrease in the overall SI (P<0.05) in the WBV group after 6 weeks of treatment (post-treatment) compared with pretreatment values (P=0.01). The percentage of improvement in SI was 49.85%.

Results of stability indexes for the Tai Chi exercise group (group B)

As shown in Table 4, there was a statistically significant reduction (P<0.05) in the SI after 6 weeks of treatment (post-treatment) in the Tai Chi group (P=0.01). The percentage of improvement in SI was 33.07%.

Between groups comparative analysis

As shown in Table 5, there was a nonsignificant difference (P>0.05) in the SI between both groups of the study before treatment. The SI of the Tai Chi exercise group showed a significant decrease after treatment (P=0.01). However, the SI in the WBV group showed a highly significant decrease after treatment when compared with the Tai Chi exercise group (P=0.0001).

Discussion

This is the first randomized controlled study comparing the efficacy of WBV and Tai Chi exercise as types of physical therapy interventions to improve postural balance in patients with lower-limb ulcers. The post-treatment balance assessment was identical to the pretreatment assessment and was performed at the beginning of the study and at the end of the study after 6 weeks for both groups. The parameter investigated in this study involved the overall SI by using the BBS. This was supported by Hinman [18]. All factors that may affect the balance and the results had been controlled for as much as possible, including age, weight, height, types of ulcer, diabetes, medical treatment, and special habits. Measurement of balance by the BBS has been carried out by Cachupe *et al.* [17], and Hinman [18] reported that the BBS has been considered reliable.

This randomized, controlled trial compared the outcome of the overall SI measures between a group that received WBV and a group that received Tai Chi exercise. The comparison of the overall SI measures between the WBV (group A) and the Tai Chi exercise (group B) groups revealed significant differences in both groups after 6 weeks of treatment, but in favor of group A (WBV group).

In the present study, the IB program, derived from the principles of Tai Chi, was used for controlling balance,

Table 2 Analysis for patient demographic data of both groups (A and B)

	Group A	Group B	*P*-value
Age (mean±SD) (years)	57.60±5.10	57.53±4.87	0.967
Weight (mean±SD) (kg)	75.47±5.76	75.60±6.21	0.21
Height (mean±SD) (cm)	160.33±5.58	159.87±6.42	0.83
Sex [*n* (%)]			
Female	7 (47)	5 (33)	
Male	8 (53)	10 (67)	

Table 3 Comparison between pretreatment and post-treatment application values of the stability index in the whole-body vibration group

	Stability index in the whole-body vibration group	
	Pretreatment	Post-treatment
Mean±SD	3.39±0.54	1.7±0.51
Maximum	4.3	2.9
Minimum	2.6	1.2
Mean difference	1.69	
Percentage of improvement	49.85	
P-value	0.0001	

Table 4 Comparison between pretreatment and post-treatment application values of the stability index in the Tai Chi exercise group

	Stability index in the Tai Chi exercise group	
	Pretreatment	Post-treatment
Mean±SD	3.78±1.1	2.53±0.47
Maximum	5.6	3.2
Minimum	1.9	1.7
Mean difference	−1.25	
Percentage of improvement	33.07	
P-value	0.01	

Table 5 Comparative analysis of the stability index between the two groups of the study

	Stability index			
	Pretreatment		Post-treatment	
	Tai Chi group	Whole-body vibration group	Tai Chi group	Whole-body vibration group
Mean±SD	3.78±1.10	3.39±0.54	2.53±0.48	1.7±0.51
Mean difference	0.39		0.83	
P-value	0.24		0.01	

as Torvinen *et al.* [64], Skelton [42], Wolf *et al.* [26], and Woollcott [43] have suggested that it is the optimal treatment schedule appropriate for elderly persons. The results of the present study demonstrated that the SI had a significant decrease (improvement) after Tai Chi exercise (post-treatment) compared with pretreatment values. This finding was consistent with those reported by Fong and Ng [44], Orr *et al.* [45], and Wolf *et al.* [26].

On the other hand, some trials failed to show any significant difference after Tai Chi exercises on balance [46,47].

Improvement in the SI after Tai Chi exercise may be the result of an increase in the proprioceptive coordination of movement, increase in kinesthetic sensation and stimulation of the vestibular system, increase in force production and muscle shear force, increase in sensory motor function, improved local dynamic stability and body awareness, and decrease of fear of falling [48,49].

The results of this study also showed that the SI in the WBV group significant decreased after treatment when compared with the Tai Chi exercise group (P=0.01). This finding was consistent with those reported by Schlee *et al.* [50], Bautmans *et al.* [51], Wunderer *et al.* [52], Gusi *et al.* [53], Bruyere *et al.* [54], and Cheung *et al.* [55].

On the other hand, some trials failed to show any significant difference of WBV on balance [56,57,58].

WBVT elicits a biological adaptation that is connected to the neural potentiation effect. In this effect, the proprioceptive pathways are strongly stimulated by the vibration, which results in reflexive muscle contractions. The neuromuscular response to vibration, known as the tonic vibration reflex, causes a temporary increase in muscular activity and proprioception [59]. Perturbations caused by platform translations stimulate sensory receptors in joints, muscles, and ligaments, which in turn can activate reflex pathways. The receptors send afferent impulses to the dorsal part of the spinal cord where the direction and amplitude of the perturbation is encoded and the appropriate response is selected, initiated, and sent directly to the appropriate muscles [60]. The improved performance in the WBV group is likely to be caused by the extensive sensory stimulation and a more efficient use of the proprioceptive feedback loop due to vibration training.

WBVT excites the primary nerve endings of the muscle spindle, which leads to a tonic contraction of the muscle. This results in an increase in synchronization of the motor unit. This motor unit synchronization leads to an activation of the afferent nerve fibers, through the reflex arcs, which causes the efferent nerve fibers to contract the muscle [61].

Humans perceive vibration through muscles and tendons and make adaptations to ease the vibration effect, through which tonic vibration reflex occurs and the neuromuscular functions are improved [62].

Many studies have confirmed the beneficial effects of WBV on the musculoskeletal system. The positive effects of vibration training on muscle strength have been reported in previous studies [28,31–36]. It has been shown to improve the knee extensor strength, vertical jump, chair-rising time, body balance, chronic back pain, and hip bone mineral density and also to increase the serum levels of testosterone and growth hormones [63].

Study limitations

A lot of effort was taken with each patient to reduce the influence of the possible errors inherent to this study. However, some limitations were present, such as the effect of environmental variables during treatment, unmentioned fatigue or pain, psychological status of the patients at the time of measurement, individual difference in patients, small sample size, difference in patient weight and its influence on the treatment program, possible human error in measurement, the level of patient co-operation with the therapist as it affects the level of understanding and the degree of patient awareness regarding the importance of the treatment, and physiological variation in wounds from patient to patient.

Further studies are needed to investigate the effect of weight-bearing distributions on the planter aspect of the sole of the foot in different types of lower-limb ulcers during static and dynamic situations by using foot scan, to compare between different types of lower-limb ulcers in relation to balance, to clarify the effect of other therapeutic exercise for better balance performance in diabetic foot ulcer patients, to determine and confirm the effect of both rehabilitation approaches on lower-limb ulcer patients, with more than 6 weeks, to augment the effect of physical training of every joint separately (hip, knee, and ankle joints) on lower-limb ulcers, to evaluate the role of sensory re-education program on balance in lower-limb ulcers, and finally to evaluate the role of vestibular stimulation on balance in lower-limb ulcers.

Conclusion

From the previous discussion of these results, and according to the reports and studies of other investigators in the field related to the present study, the authors conclude that using WBV for rehabilitation of lower-limb ulcers is more effective in the management of disturbed balance of such patients.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1 Graham ID, Harrison MD, Nelson EA, Lorimer K, Fisher A. A systematic review of prevalence studies of lower limb ulceration. Adv Skin Wound Care 2003; 16:305–316.

2 Franks PJ, McCullagh L, Moffatt CJ. Assessing quality of life with chronic venous leg ulceration using the medical outcomes short form-36 questionnaire. Ostomy Wound Manage 2003; 49:26–37.

3 Jull A, Walker A, Hackett ME. Leg ulceration and perceived health: a population base case-control study. Age Aging 2004; 33:236–241.

4 Margolis DJ, Kantor J, Santanna J, Strom BL, Berlin JA. Risk factors for delayed healing of neuropathic diabetic foot ulcers: a pooled analysis. Arch Dermatol 2000; 136:1531–1535.

5 Ramsey SD, Newton K, Blough D, McCulloch DK, Sandhu N, Reiber GE. Incidence, outcomes, and cost of foot ulcers in patients with diabetes. Diabetes Care 1999; 22β:382–387.

6 Gribble PA, Hertel J. Effect of lower extremity muscle fatigue on postural control. Arch Phys Med Rehabil 2004; 85:589–592.

7 Ducic IK, Dellon AL. Relationship between loss of pedal sensibility, balance, and falls in patients with peripheral neuropathy. Ann Plast Surg 2004; 52:535–540.

8 Horak FB, Ruth D, Robert J. Diabetic neuropathy and surface sway-referencing disrupt somatosensory information for postural stability in stance. Somatosens Mot Res 2002; 19:316–326.

9 Jerrold S, Maria C, Scott L, Everett L, Eric J. Correlation between gait and balance in people with and without type 2 diabetes in normal and subdued light. Med Sci Monit 2006; 12:CR273–CR281.

10 Joyce CJ, Perrin DH, Arnold BL, Granata KP, Gansneder BM, Gieck JH. Dorsiflexor and plantar flexor muscle fatigue decreases postural control. J Athl Train 2001; 36:S32.

11 Maluf KS, Mueller MJ. Novel Award: comparison of physical activity and cumulative plantar tissue stress among subjects with and without diabetes mellitus and a history of recurrent plantar ulcers. Clin Biomech (Bristol, Avon) 2003; 18:567–575.

12 Nalini S, David GL, Benjamin A. Preventing foot ulcers in patients with diabetes. JAMA 2005; 293:217–228.

13 Dingwell JB, Cusumano JP, Sternad D, Cavanagh P. Slower speeds in patients with diabetic neuropathy lead to improved local dynamic stability of continuous over-ground walking. J Biomech 2000; 33:1269–1277.

14 Shummway-Cook A, Woolacott MH. Motor control: theory and practical applications. Baltimore, MD: Williams & Wilkins Publishing Company; 1995.

15 Shummway-Cook A, Woolacott MH. Motor control theory and practical applications. 2nd ed. Philadelphia, PA, Lippincott Williams & Wilkins; 2001. 25–60.

16 Blackburn JT, Guskiewicz KM, Petschauer MA, Prentice WE. Balance and joint stability: the relative contributions of proprioception and muscular strength. J Sport Rehabil 2000; 9:315–328.

17 Cachupe WJ, Shifflett B, Kahanov L, Wughalter EH. Reliability of Biodex balance system measures. Meas Phys Educ Exerc Sci 2001; 5:97–108.

18 Hinman MB. Factors affecting reliability of the Biodex balance system: a summary of four studies. J Sport Rehabil 2000; 9:240–252.

19 Campbell AJ, Robertson MC, Gardner MM, Norton RN, Buchner DM. Falls prevention over 2 years: a randomized controlled trial in women 80 years and older. Age Ageing 1999; 28:513–518.

20 Gardner MM, Robertson MC, Campbell AJ. Exercise in preventing falls and fall related injuries in older people: a review of randomized controlled trials. Br J Sports Med 2000; 34:717.

21 Gillespie LD, Gillespie WJ, Robertson MC, Lamb SE, Cumming RG, Rowe BH. Interventions for preventing falls in elderly people. Cochrane Database Syst Rev 2009; 2:CD000340.

22 Moreland J, Richardson J, Chan DH. Evidence-based guidelines for the secondary prevention of falls in older adults. Gerontology 2003; 49:93–116.

23 Armstrong DG, Lavery LA, Holtz-Neiderer K. Variability in activity may precede diabetic foot ulceration. Diabetes Care 2004; 27:1980–1984.

24 LeMaster JW, Reiber GE, Smith DG. Daily weight-bearing activity does not increase the risk of diabetic foot ulcers. Med Sci Sports Exerc 2003; 35:1093–1099.

25 James KD, David SO, Steve V. A focused exercise regimen improves clinical measures of balance in patients with peripheral neuropathy. Arch Phys Med Rehabil 2001; 82:205–209.

26 Wolf SL, Barnhart HX, Kutner NG, McNeely E, Coogler C, Xu T. Reducing frailty and falls in older persons: an investigation of Tai Chi and computerized balance training. J Am Geriatr Soc 1996; 44.5:489–497.

27 Yan JH. Tai Chi practice improves senior citizens' balance and arm movement control. J Aging Phys Act 1998; 6:271–284.

28 Bosco C, Colli R, Introini E, Cardinale M, Tsarpela O, Madella A, *et al.* Adaptive responses of human skeletal muscle to vibration exposure. Clin Physiol 1999; 19:183–187.

29 Rittweger J, Beller G, Felsenberg D. Acute physiological effects of exhaustive whole-body vibration exercise in man. Clin Physiol 2000; 20:134–142.

30 Rubin C, Turner S, Mallinckrodt C, Jerome C, Mcleod K, Bain S. Mechanical strain, induced noninvasively in the high-frequency domain, is anabolic to cancellous bone, but nor cortical bone. Bone 2002; 30:445–452.

31 Torvinen S, Kannu P, Sievanen H, Jarvinen TA, Pasanen M, Kontulainen S, *et al.* Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. Clin Physiol Funct Imaging 2002; 22:145–152.

32 Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. Med Sci Sports Exerc 2003; 35:1033–1041.

33 Roelants M, Delecluse C, Verschueren SM. Whole-body-vibration training increases knee-extension strength and speed of movement in older women. J Am Geriatr Soc 2004; 52:901–908.

34 Torvinen S, Kannu P, Sievanen H, Jarvinen TA, Pasanen M, Kontulainen S, *et al.* Effect of four-month vertical whole body vibration on performance and balance. Med Sci Sports Exerc 2002; 34:1523–1528.

35 Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. J Bone Miner Res 2004; 19: 352–359

36 Rittweger J. Vibration as an exercise modality: how it may work, and what its potential might be. Eur J Appl Physiol 2010; 108:877–904.

37 Schaper NC. Diabetic foot ulcer classification system for research purposes: A progress report on criteria for including patients in research studies. Diabetes Metab Res Rev 2004; 20(Suppl 1):S90–S95.

38 Schmitz R, Arnold B. Intertester and intratester reliability of a dynamic balance protocol using the Biodex Stability System. J Sport Rehabil 1998; 7:95–101.

39 Capuno PD, Rheault W, Hukai J, Mark P. Intra-tester and inter-tester reliability of the cervical range of motion device. Arch Phys Med Rehabil 1995; 72:338–340.

40 Biodex, M. S. Biodex System 3 Pro Manual (#835-000) Applications/ Operations. Shirley, NY: Biodex Medical System; 1998.

41 Julious SA. Sample size of 12 per group rule of thumb for a pilot study. Pharm Stat 2005; 4:287–291.

42 Marjan JF, Ruud JB, Marijke JC, Piet CV. Effects of exercise programs on falls and mobility in frail and pre-frail older adults: a multicenter randomized controlled trial. Arch Phys Med Rehabil 2006; 87:885–896.

43 Skelton DA. Effects of physical activity on postural stability. Age Ageing 2001; 30:33–39.

44 Woollcott MH. Systems contributing to balance disorders in older adults. J Gerontol A Biol Sci Med Sci 2000; 55:M424–M428.

45 Fong SM, Ng GY. The effects of sensorimotor performance and balance with Tai chi training. Arch Phys Med Rehabil 2006; 87:82–87.

46 Orr R, De Vos N, Singh NA, Ross DA, Stavrinos TM, Fiatarone-Singh MA. Power training improves balance in healthy older adults. J Gerontol A Biol Sci Med Sci 2006; 61:78–85.

47 Wolf SL, Sattin RW, Kutner M, O'Grady M, Greenspan AI, Gregor RJ. Intense Tai Chi exercise training and fall occurrences in older, transitionally frail adults: a randomized, controlled trial. J Am Geriatr Soc 2003; 51:1693–1701.

48 Woo J, Hong A, Lau EM, Lynn HS. A randomized controlled trial of Tai chi and resistant exercise on bone health, muscle strength and balance in community-living elderly people. Age Ageing 2007; 36:262–268.

49 Li YC, Wong AM, Chou SW, Tang FT, Wong PY. The effect of Tai Chi Chuan on postural stability in the elderly: preliminary report. Chang Gung Med J 2001; 23:197–204.

50 Gallagher BM. Tai Chi Chuan and Qigong: physical and mental practice for functional mobility. Top Geriatr Rehabil 2003; 19:172–182.

51 Schlee G, Reckmann D, Milani TL. Whole body vibration training reduces plantar foot sensitivity but improves balance control of healthy subjects. Neurosci Lett 2012; 506:70–73.

52 Bautmans I, van Hees E, Lemper J-C, Mets T. The feasibility of whole body vibration in institutionalised elderly Persons and its influence on muscle performance, balance and mobility: a randomized controlled trial. BMC Geriatr 2005; 5:17.

53 Wunderer K, Schabrun SM, Chipchase LS. Effects of whole body vibration on strength and functional mobility in multiple sclerosis. Physiother Theory Pract 2010; 26:374–384.

54 Gusi N, Parraca JA, Olivares PR, Leal A, Adsuar JC. Tilt vibratory exercise and the dynamic balance in fibromyalgia: a randomized controlled trial. Arthritis Care Res 2010; 62:1072–1078

55 Bruyere O, Wuidart MA, Di Palma E, Gourlay M, Ethgen O, Richy F, Reginster JY. Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. Arch Phys Med Rehabil 2005; 86:303–7.

56 Cheung WH, Mok HW, Qin L, Sze PC, Lee KM, Leung KS. High-frequency whole-body vibration improves balancing ability in elderly women. Arch Phys Med Rehabil 2007; 88:852–857.

57 Ebersbach G, Edler D, Kaufhold O, Wissel J. Whole body vibration versus conventional physiotherapy to improve balance and gait in Parkinson's disease. Arch Phys Med Rehabil 2008; 89:399–403.

58 Ilse JW, Van N, Hilde L, Fanny S, Ronald M, Annet van K, *et al.* Long-term effects of 6-week whole-body vibration on balance recovery and activities of daily living in the postacute phase of stroke a randomized, controlled trial. Stroke 2006; 37:2331–2335.

59 Rogers ME, Fernandez JE, Bohlken RM. Training to reduce postural sway and increase functional reach in the elderly. J Occup Rehabil 2001; 11:291–298.

60 Carlucci F, Mazzà C, Cappozzo A. Does whole-body vibration training have acute residual effects on postural control ability of elderly women? J Strength Cond Res 2010; 24:3363–3368.

61 Roberts TD. Reflex balance. Nature 1973; 244:156–158.

62 Jordan MJ, Norris SR, Smith DJ, Herzog W. Vibration training: an overview of the area, training consequences, and future considerations. J Strength Cond Res 2005; 19:459–466.

63 Cardinale M, Bosco C. The use of vibration as an exercise intervention. Exerc Sport Sci Rev 2003; 31:3–7.

64 Torvinen S, Kannus P, Sievanen H, Jarvinen TA. Effect of four-month vertical whole body vibration on performance and balance. Med Sci Sports Exerc 2002; 34:1523–1528.