Whole-body vibration improves ankle spasticity, balance, and walking ability in individuals with incomplete cervical spinal cord injury

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Abstract

OBJECTIVES: This study aimed to investigate the effects of whole-body vibration (WBV) training on ankle spasticity, balance, and walking ability in patients with incomplete spinal cord injury (iSCI) at cervical level.

METHODS: Twenty-eight patients with cervical iSCI were randomly assigned to WBV (n = 14) or control group (n = 14). WBV group received WBV training, while control group was treated with placebo-treatment. All interventions were given for 20-min, twice a day, 5-days a week for 8-weeks. The spasticity of ankle plantar-flexors was assessed by estimating passive resistive force using a hand-held dynamometer. Balance was analyzed based on postural sway length (PSL) using a force plate. Timed-Up and Go test (TUG) and 10 m-Walk Test (10MWT) were used to assess walking ability.

RESULTS: Both groups showed significant improvements in spasticity, balance and walking ability. Also, the significant differences between two groups were demonstrated in the outcomes of spasticity (3.0 ± 1.7 vs 0.9 ± 1.2), PSL (6.4 ± 1.2 vs 3.2 ± 0.9 with eyes-open, and 15.1 ± 10.9 vs 7.4 ± 4.3 with eyes-closed), TUG (2.3 ± 1.3 vs 1.0 ± 1.0), and 10MWT (3.5 ± 2.3 vs 1.3 ± 1.4).

CONCLUSIONS: WBV may be a safe and effective intervention to improve spasticity, balance and walking ability in individuals with cervical iSCI. Thus, WBV may be used to improve these symptoms in clinics.

Keywords: Balance, incomplete spinal cord injury, whole body vibration

1. Introduction

According to a review study of the incidence of spinal cord injury (SCI), the proportion of cervical injuries is increasing, but the proportion of neurologically complete injuries is decreasing (Devivo, 2012). Approximately 59% of all spinal injuries are incomplete (National Spinal Cord Injury Statistical Center, 2013).
Individuals with iSCI have problems with postural balance and walking ability because of motor and sensory impairments (Ness & Field-Fote, 2009; Ditunno, Patrick, Stineman, & Ditunno, 2008). Also, altered muscle activity and recruitment timing, and co-contraction after iSCI lead to walking abnormalities (Krawetz & Nance, 1996). However, individuals with iSCI show significant functional recovery, even though spontaneous regeneration of damaged fibers is limited in the central nervous system (CNS). This is because synaptic plasticity in pre-existing pathways, and the formation of new circuits through collateral sprouting of nerve fibers, might occur in cortical and subcortical motor centers, in the spinal cord below the lesion, and in the spared fiber tracts. Therefore, rehabilitation in iSCI needs to focus not only on compensation for impairment, but also on maximizing the potential for motor recovery (Raineteau & Schwab, 2001).

Whole body vibration (WBV) has been studied in various populations. Current evidence suggests that WBV might be a potential intervention for improving muscle strength (Nordlund & Thorstensson, 2007), bone mineral density (Lau et al., 2011; Wysocki, Butler, Shamiyan, & Kane, 2011), balance function, and mobility in aging adults or patients with neurological disease (Lam, Lau, Chung, & Pang, 2012; Mikhael, Orr, & Fiatarone, 2010; Merriman & Jackson, 2009). The use of WBV in SCI has also been associated with changes in spasticity and walking function (Ness & Field-Fote, 2009). Vibration effects on spasticity might activate presynaptic inhibition of Ia-afferents, which reduces the release of neurotransmitters to the motor neurons, resulting in inhibition of the H-reflex amplitudes; thus WBV training may potentially increase ambulatory capacity by reducing ankle plantar flexion spasticity (Chan et al., 2012). However, there is limited published evidence to guide clinicians in determining appropriate, valid, and reliable outcome measures for the use of WBV in clinical trials and for clinical decision-making. To our knowledge, no study has directly determined correlations between changes of ankle spasticity and improvements in postural balance and walking ability through WBV intervention in individuals with iSCI.

Therefore, the purpose of this study was to determine the effects of WBV on ankle spasticity, balance, and walking ability in patients with clinical iSCI at the cervical level by using standardized WBV training and assessment tools.

2. Methods

2.1. Participants

This study was a double blind, randomized clinical trial. All study procedures were performed at a rehabilitation center located in Seoul, South Korea. The following inclusion criteria were used: (1) diagnosed with cervical level 6 or 7 iSCI, (2) onset ≥6 months, (3) American Spinal Injury Association Impairment Scale (AIS) grade D motor and sensory scores, (4) ability to stand for at least 5 min, (5) ability to understand and follow verbal commands, (6) medical referral by a physician for physical therapy, and (7) ability to complete designed WBV training session. Patients with pre-existing neurological disorders, progressive SCI, brain injury, cardiopulmonary complications, or other concurrent medical conditions were excluded. Those taking medication that could interfere with postural control were also excluded. Thirty-eight patients who were diagnosed with iSCI were initially recruited for this study. Among these, 32 out of 38 patients fulfilled the selection criteria. During the intervention period, four dropped out of the study because of discharge before the intervention period or personal issues. Patients signed a written informed consent that explained the protocol prior to data collection, and the ethical committee of Gachon University approved this study.

All patients were randomly assigned to two groups: (1) the WBV group (n = 16) or (2) the control group (n = 16). Randomization was intended to minimize order effect. No baseline differences between the two groups were detected for primary outcome measures of spasticity, balance, and walking (paired t tests, all P > 0.05). To ensure masking, we did not reveal protocols and intervention order to clinical evaluators. Intervention allocation was recorded in a password protected document to maintain blinding. All data were measured by the same blinded evaluator before training began and at the end of the eight-week training period.

2.2. Intervention

The patients in both groups participated in scheduled programs conducted by two trained physical therapists. The Patients in the WBV group received WBV training with conventional physical therapy, and were required to complete 80 sessions over 8 weeks; those in the control group received placebo-
WBV training with conventional physical therapy over the same time period. Twenty-eight patients ultimately completed all intervention sessions as shown in Fig. 1. Four dropped out of the study because of discharge before the intervention period or personal issues.

The WBV group received 16 minutes of WBV training, twice a day, 5 days a week for 8 weeks. The control group received placebo-WBV training without vibration. The WBV device (TT2590X7, TurboSonic Co., South Korea) consisted of a moveable platform that generated rapid oscillating movements and a support bar. To apply an intervention, the frequency was set at 30 Hz, and a vertical displacement was 2–4 mm. Patients were required to stand on the platform with their feet at an equal and standardized distance from axis, and were instructed to hold a semi-squatting position, with slight flexion (140°) at hips, knees, and ankles, to concentrate the vibrations at the pelvic level. Patients were allowed to hold the support bar for safety. WBV training consisted of four sets of 45 seconds of stimulation, and a minute break between each session. In this way, a total of 80 training sessions were provided to each patient. Participants in the control group received 16 minutes of placebo-intervention. The controls were required to follow the same procedure as for WBV training. The physical therapist explained that placebo-intervention was an ultra-low frequency vibration, so it might be difficult for a patient to define what they feel.

Conventional physical therapy was supervised by two therapists. Both groups were treated with a conventional physical therapy protocol consisting of range of motion exercise, mat exercise, and gait training for 30 minutes per day during the same period as the intervention. To minimize the therapeutic effects from different physical therapists, patients received instruction in the designated protocol 9-times before and during the intervention period.

2.3. Outcome measures

The spasticity of ankle plantar-flexor was calculated by estimating passive resistive force using a Hand-held dynamometer (01163, Lafayette Instruments, USA). In this study, the dynamometer was used to measure the resistive force following spasticity (Lamontagne, Malouin, Richards, & Dumas, 1998). The evaluator asked patients to lay comfortably supine, and measured maximal resistance-force (kg) during passive dorsiflexion to maximal range of motion, by grasping the head of dynamometer perpendicular to the forefoot.

Postural imbalance was analyzed based on postural sway length (PSL, cm) using a force plate.
device (PDM Force Plate, Zebris, Germany). The force plate device measured the static and dynamic pressure of standing feet (1~120 N/cm², 2~5 Hz) by force sensors embedded on a plate (32 x 47 cm). Patients were instructed to stand on the plate with their arms down to the side. When measured with eyes opened (EO) and closed (EC), they stared at a point with a diameter of 15 cm that was placed 3 m in front of them. An assistant stood alongside for safety. Patients positioned their feet 8 cm apart between the two medial malleoli at an angle between the feet of 10°. Total sway length was measured three times over 30 seconds, and mean values were calculated.

The TUG and the 10MWT were used to test walking ability. These metrics have acceptable inter-rater and intra-rater reliability in SCI individuals (van Hedel, Wirz, & Dietz, 2005). To measure the TUG, patients were required to stand-up from a chair with armrests, walk 3 m, turn around, return to the chair, and sit-down. The evaluator measured the time taken to complete this task in seconds with a digital stopwatch. In the 10MWT, tape was placed on the floor to mark the course, with an additional 10 m at the beginning and end to permit acceleration and deceleration; patients were instructed to walk at a comfortable maximum speed. The evaluator asked patients to walk 10 m as quickly but safely as possible for 3 trials. A rest period was provided after each of the 3 trials.

2.4. Data analysis

Statistical analysis was performed using SPSS 23.0. The normal distributions of the results were tested with the Shapiro-Wilk test. Two-by-two mixed factorial analysis of variance (ANOVA) was conducted to compare pre- and post-test (time) with respect to the effect of whole body vibration (intervention) on spasticity, postural sway, TUG, and 10MWT. The paired $t$-test was used as a simple effects analysis in each group when there was a significant interaction between the intervention and the time. The differences between the two groups were compared with independent sample $t$-tests. Results were accepted as statistically significant at $p < 0.05$. We used Pearson correlation coefficients for spasticity, postural balance, and walking ability.

3. Results

The general characteristics of the 28 patients are shown in Table 1.

A mixed factorial ANOVA yielded a significant interaction between the intervention (experimental vs. control group) and the time (pre- and post-test) on spasticity (Right side; $F(1,26)=12.871$, $p = 0.001$, Left side; $F(1,26)=14.965$, $p = 0.001$). A simple effects analysis for the intervention indicated that the means between the pre- and post-test significantly improved both the experimental group (Right side; 11.9 ± 3.5 vs. 8.8 ± 2.9, $p < 0.001$, Left side; 13.2 ± 2.3 vs. 10.1 ± 2.2, $p < 0.001$) and control group (Right side; 12.2 ± 3.2 vs. 11.1 ± 2.9, $p < 0.001$, Left side; 12.5 ± 3.1 vs. 11.6 ± 2.3, $p = 0.013$) (Table 2).

A significant interaction between the intervention and the time on PSL with EO and EC was found (EO; $F(1,26)=4.426$, $p = 0.045$, EC; $F(1,26)=6.995$, $p = 0.014$). PSL significantly decreased between pre- and post-test in both the experimental (EO; 56.1 ± 2.2 vs. 49.7 ± 1.8, $p < 0.001$, EC; 73.1 ± 16.5 vs. 58.0 ± 8.2, $p < 0.001$) and control group (EO; 59.7 ± 3.1 vs. 56.5 ± 2.6, $p = 0.002$, EC; 72.3 ± 13.8 vs. 64.9 ± 10.5, $p < 0.001$) (Table 3).

Similarly, there was a significant interaction between the intervention and the time on TUG score ($F(1,26)=6.679$, $p = 0.016$) and 10MWT ($F(1,26)=9.663$, $p = 0.005$). A simple effects analysis for the intervention showed that there were significant decreases on TUG score and 10MWT both the experimental group (TUG; 13.7 ± 3.2 vs. 11.4 ± 2.8 $p < 0.001$, 10MWT; 29.3 ± 9.0 vs. 25.8 ± 8.1, $p < 0.001$) and the control group (TUG; 14.7 ± 4.5 vs. 13.7 ± 4.1, $p = 0.001$, 10MWT; 28.8 ± 7.2 vs. 27.5 ± 6.3, $p = 0.005$) (Table 4).

The main findings of this study were that the outcomes of spasticity, PSL, TUG, and 10MWT in both groups were significantly changed, when comparing differences between before and after intervention within each group. There were also significant differences between the WBV and control groups for the changes in plantar flexor spasticity ($p = 0.001$), PSL ($p = 0.045$ with EO and $p = 0.014$ with EC), TUG ($p = 0.016$), and 10MWT ($p = 0.005$) (Tables 2, 3 and 4); there were also strong correlations between spasticity and PSL with EO (CC = 0.505, $p = 0.066$), PSL with EC (CC = 0.831, $p = 0.000$), TUG (CC = 0.708, $p = 0.005$), and 10MWT (CC = 0.746, $p = 0.002$) (Table 5).

4. Discussion

Our results provide evidence that the use of WBV holds promise as a safe and effective intervention to
Table 1
General characteristics of the participants

<table>
<thead>
<tr>
<th>Variable</th>
<th>WBV group (n = 14)</th>
<th>Control group (n = 14)</th>
<th>X²/t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (Male/Female)</td>
<td>14 (9/5)</td>
<td>14 (10/4)</td>
<td>0.391a</td>
<td>0.699</td>
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<tr>
<td>Age (years)</td>
<td>46.1 ± 9.8</td>
<td>49.9 ± 9.3</td>
<td>1.048b</td>
<td>0.304</td>
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<tr>
<td>Height (cm)</td>
<td>169.0 ± 9.4</td>
<td>170.6 ± 10.5</td>
<td>0.438</td>
<td>0.665</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70.9 ± 10.4</td>
<td>74.8 ± 11.5</td>
<td>0.931</td>
<td>0.360</td>
</tr>
<tr>
<td>Duration (months)</td>
<td>13.7 ± 3.2</td>
<td>14.3 ± 4.9</td>
<td>0.365</td>
<td>0.718</td>
</tr>
</tbody>
</table>

All values are expressed as mean ± standard deviation (SD). a chi-squared test, b independent t-test.

Table 2
Changes in spasticity measured by a manual muscle tester (kg)

<table>
<thead>
<tr>
<th>Side</th>
<th>WBV group (n = 14)</th>
<th>Control group (n = 14)</th>
<th>Time x Group Interaction</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>Pre 11.9 ± 3.5</td>
<td>12.2 ± 3.2</td>
<td>0.001</td>
<td>0.276</td>
<td>0.785</td>
</tr>
<tr>
<td></td>
<td>Post 8.8 ± 2.9</td>
<td>11.1 ± 2.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-Pre −3.1 ± 1.9</td>
<td>−1.1 ± 0.6</td>
<td>3.581</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>Pre 13.2 ± 2.3</td>
<td>12.5 ± 3.1</td>
<td></td>
<td>0.001</td>
<td>0.526</td>
</tr>
<tr>
<td></td>
<td>Post 10.1 ± 2.2</td>
<td>11.6 ± 2.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-Pre −3.0 ± 1.7</td>
<td>−0.9 ± 1.2</td>
<td>3.869</td>
<td>0.001</td>
<td></td>
</tr>
</tbody>
</table>

All values are expressed as mean ± standard deviation (SD); a indicates a significant difference compared to pre-value within the group, and b indicates a significant difference compared to the value of the control group.

Table 3
Changes in static balance function measured by postural sway length (cm)

<table>
<thead>
<tr>
<th>Condition</th>
<th>WBV group (n = 14)</th>
<th>Control group (n = 14)</th>
<th>Time x Group Interaction</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes open</td>
<td>Pre 56.1 ± 2.2</td>
<td>59.7 ± 3.1</td>
<td>0.045</td>
<td>0.964</td>
<td>0.344</td>
</tr>
<tr>
<td></td>
<td>Post 49.7 ± 1.8</td>
<td>56.5 ± 2.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-Pre −6.4 ± 1.2</td>
<td>−3.2 ± 0.9</td>
<td>2.104</td>
<td>0.045</td>
<td></td>
</tr>
<tr>
<td>Eyes closed</td>
<td>Pre 73.1 ± 16.5</td>
<td>72.3 ± 13.8</td>
<td>0.014</td>
<td>0.275</td>
<td>0.786</td>
</tr>
<tr>
<td></td>
<td>Post 58.0 ± 8.2</td>
<td>64.9 ± 10.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-Pre −15.1 ± 10.5</td>
<td>−7.4 ± 4.3</td>
<td>2.645</td>
<td>0.014</td>
<td></td>
</tr>
</tbody>
</table>

All values are expressed as mean ± standard deviation (SD); a indicates a significant difference compared to pre-value within the group, and b indicates a significant difference compared to the value of the control group.

Table 4
Changes in dynamic balance and gait ability by TUG and 10MWT

<table>
<thead>
<tr>
<th>WBV group (n = 14)</th>
<th>Control group (n = 14)</th>
<th>Time x Group Interaction</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>TUG (s)</td>
<td>Pre 13.7 ± 3.1</td>
<td>14.7 ± 4.5</td>
<td>0.016</td>
<td>0.519</td>
</tr>
<tr>
<td></td>
<td>Post 11.4 ± 2.8</td>
<td>13.7 ± 4.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-Pre −2.3 ± 1.3</td>
<td>−1.0 ± 1.0</td>
<td>2.584</td>
<td>0.016</td>
</tr>
<tr>
<td>10MWT (s)</td>
<td>Pre 29.3 ± 9.0</td>
<td>28.8 ± 7.2</td>
<td>0.005</td>
<td>0.167</td>
</tr>
<tr>
<td></td>
<td>Post 25.8 ± 8.1</td>
<td>27.5 ± 6.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-Pre −3.5 ± 2.3</td>
<td>−1.3 ± 1.4</td>
<td>3.108</td>
<td>0.005</td>
</tr>
</tbody>
</table>

All values are expressed as mean ± standard deviation (SD); a indicates a significant difference compared to pre-value within the group, and b indicates a significant difference compared to the value of the control group.

decrease spasticity and improve balance and walking function in individuals with iSCI at the cervical level. All subjects who performed WBV training had decreased spasticity of the ankle plantar flexors, and showed improved balance and walking ability after 4 weeks of WBV intervention.

We used WBV with a frequency of 30 Hz, peak-to-peak displacement of 1.2 mm, peak acceleration of 25.00 m s⁻², and gravitational force of 3.00 g; patients performed WBV training with a knee angle of 140°. Alizadeh-Meghrazi, Masani, Popovic & Craven (2012) examined the impact of frequency,
amplitude, and posture on lower extremity vibration propagation among men with chronic SCI during WBV intervention. They identified optimal WBV conditions, which included the Whole Body Advanced Vibration Exercise (WAVE) platform with a knee angle of 140°, plate frequency of 45 Hz, and amplitude of 1.2 mm, and determined that variations in frequency generated the most significant changes in outcome measurements, followed by variations in knee angle and amplitude. They noted that 45 Hz vibration met optimal WBV conditions for the greatest attenuation of vibration in the lower extremities, while minimizing vibration to the head. When compared with their protocol of WBV, our platform frequency of 30 Hz was lower than in their study. Although there was a difference in frequency, we investigated the positive vibration effects at 30 Hz without any serious adverse events.

The finding of spasticity reduction after vibration was similar to that in the previous study, which demonstrated the possible benefits of vibration training for spasticity in patients with stroke. Pang, Lau, & Yip (2013) investigated the effects of 8-week WBV training on bone turnover, leg muscle strength, motor function, and spasticity, among chronic stroke patients. The WBV protocol used in their study did not induce effects on bone turnover, knee muscle strength, or paretic leg motor function among chronic stroke patients. However, spasticity of the paretic knee was significantly reduced in the WBV group, but not in controls. Our result of reduced spasticity is also consistent with previous reports, in that vibration may decrease spasticity through modulation of spinal motoneuronal excitability in individuals with SCI. A randomized, controlled study by Chan et al. (2012) found that a single session of WBV training can reduce ankle plantar flexor spasticity in chronic stroke patients, thereby potentially improving walking capacity. They explained the possible mechanism that vibration has a positive effect on spasticity by affecting presynaptic inhibition. Presynaptic inhibition of Ia-afferents reduces the release of neurotransmitters to the motoneurons, and thereby weakens the effects of Ia-afferents on motoneurons, resulting in inhibition of the H-reflex amplitudes. Sayenko et al. (2010) described inhibitory effects of local vibration during passive standing on the soleus H-reflex among men with SCI; their results suggested that acute modulation of spinal motoneuronal excitability during WBV can be achieved in the absence of voluntary leg muscle contractions.

Interestingly, the control group also showed a significant reduction in spasticity following placebo-WBV. Participants in this group received conventional physical therapy including range of motion exercise, mat exercise and gait training. Thus, it can be suggested this anti-spastic effect comes from exercise intervention. However, additional WBV intervention played an effective role in improving this effect.

Based on previous studies, many researchers have reported the beneficial effects of WBV training on balance and walking ability (Cheung et al., 2007; Törvinen et al., 2002). When compared with the control group, the WBV group showed significantly improved scores in all measured outcomes. PSL results in the WBV group showed significant improvement after treatment. The forceplate data showed that the degree of body weight shifting diminished after vibration training, regardless of whether eyes were open or closed. The data reflected better postural balance in patients with iSCI after WBV training, which might be due to decreased plantar flexor spasticity. In addition, our TUG and 10MWT indicated that walking speed significantly increased after vibration training. Based on the results of this study, the improvement of walking ability after WBV training is considered a result of neural plastic change. Wirth et al. (2013) performed severe compression SCI in rats, followed by daily WBV over a 12 week post-injury period. They found that WBV has a significant influence on body weight support during overground locomotion, and restored the density of synaptic terminals in the spinal cord.

We also found strong correlations between spasticity, postural balance, and walking ability. A recent observational study by Scivoletto et al. (2008) determined a negative effect of spasticity on walking performance. They evaluated the effects of neurologic and non-neurologic factors on walking level and performance in patients with chronic SCI, and noted that strength, balance, and spasticity were strongly correlated with walking performance. Their results concur

### Table 5

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Pearson Correlation Coefficient</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMT vs. EO</td>
<td>0.505</td>
<td>0.066</td>
</tr>
<tr>
<td>MMT vs. EC</td>
<td>0.831</td>
<td>0.000</td>
</tr>
<tr>
<td>MMT vs. TUG</td>
<td>0.708</td>
<td>0.005</td>
</tr>
<tr>
<td>MMT vs. 10MWT</td>
<td>0.746</td>
<td>0.002</td>
</tr>
</tbody>
</table>

MMT, Manual muscle test; EO, Eyes open static balance; EC, Eyes closed static balance; TUG, Timed Up and Go test; 10MWT, 10 meter walk test.
with ours. Thus, ankle spasticity can be the best predictor of walking features, and decreasing spasticity may have a positive effect on walking ability.

This study has some limitations. First, participants with a limited cervical level (C6/7) of spinal cord injury were examined. Second, the sample size for participants was relatively small. Third, we only measured one frequency (30 Hz) commonly used in clinical practice; hence, future studies should consider the use of various vibration frequencies to determine the standard parameter.

Acknowledgments

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Conflict of interest

The authors declare that there were no conflicts of interest.

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