Effects of Whole-Body Vibration on the Improvement of Balance, Gait and Activities of Daily Living in Patients with Subacute Stroke

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Objective: The purpose of this study was to investigate the effects of whole-body vibration on the improvement of functional performance in subacute stroke patients.

Methods: Twenty subacute stroke patients were equally randomized to either a vibration or a control group and received 4-week conventional rehabilitation therapy and standing exercise. During the standing exercise, the vibration group received 10-minute whole-body vibration and the control group performed standing exercise without vibration. Outcome variable included the Korean version of Berg Balance Scale (BBS), the manual muscle test (MMT) of the paretic knee extensor, Modified Ashworth Scale (MAS) of the paretic ankle plantar flexor spasticity, Functional Ambulation Category (FAC), and the Korean version of Modified Barthel Index (MBI) before and after 4-week intervention.

Results: After the 4-week intervention, the difference in BBS between groups was significant, which was significantly larger in the vibration group than in the control group. Significant differences in FAC and MBI were also observed between groups. The change of the FAC, total MBI, and mobility MBI were significantly higher in the vibration group than in the control group. MMT and MAS did not show significant difference after intervention between groups. Differences in BBS were strongly positively correlated with FAC and mobility MBI, and were moderately correlated with both of total MBI and self-care MBI.

Conclusion: Additional whole-body vibration intervention may efficiently improve balance control and ambulation in subacute stroke patients.

Keywords: Stroke; Vibration; Balance

INTRODUCTION

Stroke usually causes impairments in variety of areas, such as cognition, emotion, motor, and sensory, and thereafter results in imbalance and gait disability as well as impairment of the activities of daily living (ADLs) [1]. Among those areas, poor balance control have an negative influence on the recovery of gait and motor function [2–4], even if motor recovery progresses to some extent [5]. Many therapeutic interventions, such as visual feedback training [6], robotic devices [7], mirror therapy [8], and motor imagery training [9] have been performed to improve balance control. Those methods have limitations. Some intervention need large space for bulky equipment and others are usually hard to be applied to patients with severe functional impairments.

Recently, whole-body vibration (WBV) therapy has been attempted to improve balance control and functional performance in various groups. In WBV therapy, vibratory stimuli of various intensities composed of frequencies and amplitudes are transmitted to the body on the vibration platform. Two main neurophysiological responses of the muscle to vibrations are proposed: tonic vibration reflex and phasic reflex suppression. Vibrating the muscle appears to elicit an excitatory effect in the α-motor neuron, either by Ia or II afferent pathway, causing contractions of the homonymous muscle. During the reflex contraction, the muscle activity decrease might be caused by presynaptic inhibition of the Ia afferents, a reduction in the sensitivity of primary spindle endings and transmitter depletion [10]. In addition, Mileva et al. [11] argued that WBV during exercise was related to increased cortico-
spinal excitability and alteration of intracortical process but did not demonstrate the precise neural mechanisms of the physiological effects of WBV. Previous studies have shown that WBV therapy improves muscle power, balance, motor capacity, gait, and self-reported quality of life in sub-populations, and the effects are even more pronounced in elderly people, although the optimal WBV protocol is unknown. The improvement in the lower extremity muscular performance may be associated with an increase in the body balance [10,12]. In addition, some studies demonstrated that WBV training is safe and feasible in elderly people [13].

The positive effect of WBV therapy on the balance or gait recovery in patients with a stroke has been reported in some studies. Van Nes et al. [14] reported that one series of four consecutive repetitions of 45-second WBV with 30 Hz oscillations at 3 mm of amplitude reduced the root mean square center-of-pressure velocity in the anteroposterior direction and increased weight-shifting speed in ischemic stroke patients with an ability to stand independently. In addition, the spasticity of the paretic knee extension strength in chronic stroke patients with an ability to stand independently. Most of the participants that were enrolled in that study were patients with a chronic stroke who had regained some balance control and ambulatory function with mild to moderate impairment.

In contrast, Marin et al. [18] demonstrated that there were no significant change in both the Berg Balance Scale (BBS) and isometric contraction of the knee extensors after 17 sessions WBV with an increase in frequency (range, 5 to 21 Hz), sets (range, 4 to 7), and time per set (range, 30 to 60 seconds). Also, Brogåråd et al. [19] reported that WBV training was not efficient in improving neuromuscular and gait performance in chronic stroke patients. Most of the participants that were enrolled in that study were patients with a chronic stroke who had regained some balance control and ambulatory function with mild to moderate impairment.

We predicted that during early stage of rehabilitation, WBV intervention has an efficient influence on the improvement of balance and then functional ambulation and ADLs in stroke patients, even if their functional impairments are severe. Therefore, we performed the present study to investigate the effects of WBV intervention on the improvement of balance control and the functional performance in severely impaired stroke patients during subacute period.

**MATERIALS AND METHODS**

1. **Participants**

This study was a single-blinded randomized controlled intervention trial for patients with subacute stroke who had been admitted to Soonchunhyang University Gumi Hospital. The inclusion criteria were as follows: (1) the first onset of stroke confirmed by computed tomography or magnetic resonance imaging scan, (2) a stroke onset period less than 6 weeks, and (3) a severe gait disturbance (Functional Ambulation Category [FAC] of 0 or 1). Exclusion criteria were as follows: (1) an inability to abide with the study follow-up protocol, (2) an acute thrombotic disorder, (3) a severe cardiovascular disease, (4) a chronic obstructive pulmonary disease, (5) a cardiac pacemaker, (6) a seizure disorder, (7) a recent fracture history, (8) an acute hernia, (9) a tumor, (10) lower extremity arthralgia or back pain, (11) pregnancy, (12) a kidney disease, and (13) a gall bladder disease.

2. **Randomization**

We met all the patients who were diagnosed of suffering from a stroke and had received rehabilitation treatments at the rehabilitation center in the hospital and performed their medical examination. Patients who met both of the inclusion and exclusion criteria were numbered by the order of their recruitment. The odd-numbered ones were assigned to the WBV group, and the even-numbered ones, to the control group. The reasons for using this randomization method were as follows: (1) the number of patients who met the inclusion criteria was expected to be small and (2) the time for contacting each patient varied. In total, 20 patients who fitted the inclusion criteria and agreed to participate in the present study were divided into the WBV group (n = 10) and control group (n = 10).

3. **Intervention**

All participants in both the groups underwent an equal degree of conventional stroke rehabilitation program consisting of physical therapy, occupational therapy, and a standing exercise 5 days a week during 4 weeks. They performed the standing exercise on a side-alternating WBV device, Galileo Med S (Novotec Medical GmbH, Pforzheim, Germany), for 30 minutes during each session. While standing on the WBV platform, the participants were supported with a buttock belt for safety and were instructed to maintain a position with a slight flexion of the hips and knees in order...
to dampen the vibrations at trunk level (Fig. 1). When the participants of the WBV group were in the middle of their standing exercise, vibration stimuli were transmitted to the foot platform for 10 minutes. The WBV intervention frequency and amplitude range were 20–30 Hz and 2–3 mm, respectively. The control group, on the other hand, performed the standing exercise on the same WBV platform as the WBV group but were not exposed to the 10-minute vibration stimuli (power off). In both groups, every intervention session was supervised, and any adverse events were closely monitored by an experienced physical therapist throughout the study period.

4. The outcome measures

Before the intervention all the participants were evaluated following baseline characteristics: age, sex, type of stroke, side of hemiplegia, duration of stroke, Mini-Mental State Examination (MMSE), and somatosensory evoked potential (SSEP). The selected primary outcome measure was the Korean version of Berg Balance Scale (K-BBS) for assessing balance. The secondary outcome measures were a manual muscle test (MMT) for assessing the paretic knee extensor strength, a Modified Ashworth Scale (MAS) for the paretic ankle plantar flexor spasticity, a FAC for the walking ability, and the Korean version of the Modified Barthel Index (K-MBI) for ADLs. K-MBI was evaluated in three forms: total MBI, self-care MBI (personal hygiene, bathing, feeding, dressing, toilet), and mobility MBI (stair climbing, ambulation). The primary and secondary outcome variables were evaluated before and after 4-week intervention.

1) Balance

Postural control was evaluated by using the K-BBS. It consists of a 14-item scale that assesses the patient’s ability to maintain static and dynamic balance for a specified duration of time. The items are scored from 0 to 4, and the total score ranges from 0 to 56. A better balance ability is indicated by a higher score. The K-BBS has shown good reliability, validity, and responsiveness to change among stroke patients [20].

2) Spasticity

The MAS is a 6-point ordinal scale and is used to assess resistance to passive movements in the ankle plantar flexion on the paretic leg (0 = no spasticity, 4 = affected part rigid). It is a widely used tool to evaluate muscle tone in stroke research and has shown acceptable reliability (Kendall’s tau correlation = 0.847) [21,22].

3) Walking ability

The FAC, a clinical gait assessment scale first described by Holden et al. [23], is an ordinal scale with six evaluation levels of gait capacity (from category 0, a nonfunctional ambulation in which the patient is unable to walk to category 5, an independent ambulation in which the patient is able to walk unaided). Classification by the scale has excellent reliability, good concurrent and predictive validity, and good responsiveness in patients with hemiplegia after a stroke; therefore, it is used as the outcome measure for walking recovery [24,25].

4) Activities of daily living

The K-MBI was used to evaluate the performance of ADLs in every participant. The MBI with a 5-step scoring system evaluates the patient’s performance in basic daily activities such as personal hygiene, bathing, feeding, dressing, toilet, bladder and bowel control, chair/bed transfer, ambulation, and stair climbing. It is a reliable and valid tool for measuring the functional performance of

![Fig. 1. Standing posture of the participant on the whole-body vibration (Galileo Med S) platform. Participant’s buttocks are supported by buttock belt with hips and knees in slight flexion.](image-url)
ADLs in patients after a stroke [26].

5. The statistical analysis

Van Nes et al. [27] showed that 6-week WBV can improve the BBS, from 23.9 ± 14.8 to 40.6 ± 12.8, in the postacute phase of stroke (effect size = 1.21). Sample size was determined using G*Power 3.1 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). Based on an alpha value of 0.05 and a statistical power of 0.8, a minimum of 10 subjects would be required for each intervention group.

General characteristics of the participants were summarized as a median and interquartile range for quantitative variables and frequency (percentage) for qualitative variables. To decipher the statistical significance of the differences in the groups, Fisher’s exact test for the categorical variable and the Mann-Whitney U-test for the continuous variable were used. Wilcoxon’s signed rank test was conducted to compare the evaluation measurements before and after the WBV intervention for each group. Spearman’s rank correlation was used to investigate the correlation among factors that showed significant differences before and after the WBV intervention. A P-value less than 0.05 was considered as statistically significant. All the statistical analyses were performed using SPSS ver. 14.0 (SPSS Inc., Chicago, IL, USA) and R ver. 3.13 (The R Foundation for Statistical Computing, Vienna, Austria).

6. Ethics

This study was approved by the Institutional Review Board of Soonchunhyang University Gumi Hospital according to the Declaration of Helsinki (IRB approval no., 2016-10). A written informed consent about the study was obtained from every participant before his or her enrollment.

RESULTS

1. The participants’ characteristics

In total, 20 participants were randomly allocated to either the WBV group (n = 10) or the control group (n = 10). All of them underwent a pre-WBV intervention assessment. Of these, two participants could not be followed-up with because one in the WBV group was diagnosed as small intestine perforation before the intervention and the other in the control group got out of the hospital, irrespective of the present study. A total of 18 participants completed the intervention and post-WBV intervention assessment. Fig. 2 shows the flow of the participants.

The baseline characteristics and pre-WBV intervention values of the outcome variables are shown in Table 1. The median age of the WBV group, consisting of six males and three females, was 66.0 years, and that of the control group, consisting of four males and five females, was 71.0 years, which did not differ significantly. The proportion of an ischemic stroke was higher than that of a hemorrhagic stroke and the median duration after the stroke onset was 21.0 days in both the groups. The differences in both the groups were not significant with respect to the baseline characteristics, MMSE, SSEP, the paretic knee extensor strength, the paretic

![Fig. 2. Flow chart of participants. WBV, whole-body vibration.](http://jsms.sch.ac.kr)
ankle plantar flexor spasticity, K-BBS, FAC, or K-MBI (total, self-care, mobility) at the pre-WBV intervention assessment (P > 0.05).

Inter-group differences on the paretic knee extensor strength, the paretic ankle plantar flexor spasticity, K-BBS, FAC, total K-MBI, self-care K-MBI, and mobility K-MBI between pre-intervention and post-intervention are shown in Table 2.

### 2. The Berg Balance Scale

The BBS scores showed significant differences before and after the intervention in both the groups, from 3.0 (1.0–5.0) to 35.0 (11.0–41.0) for the WBV group (P < 0.05) and from 5.0 (3.0–12.0) to 21.0 (12.0–21.0) for the control group (P < 0.05). Furthermore, the difference in the BBS scores of the WBV group was signifi-

### Table 1. Baseline characteristics and pre-WBV intervention values of outcome variables

| Characteristic                                      | WBV (n = 9)          | Control (n = 9)         | P-value |
|-----------------------------------------------------|----------------------|-------------------------|---------|
| Age (yr)                                            | 66.0 (56.0–76.0)     | 71.0 (66.0–73.0)        | 0.894*  |
| Sex                                                 |                      |                         | 0.635*  |
| Male                                                | 6 (66.7)             | 4 (44.4)                |         |
| Female                                              | 3 (33.3)             | 5 (55.6)                |         |
| Type of stroke                                      |                      |                         | 1<sup>st</sup> |
| Hemorrhage                                          | 2 (22.2)             | 1 (11.1)                |         |
| Infarction                                           | 7 (77.8)             | 8 (88.9)                |         |
| Side of hemiplegia                                  |                      |                         | 1<sup>st</sup> |
| Right                                               | 4 (44.4)             | 5 (55.6)                |         |
| Left                                                | 5 (55.6)             | 4 (44.4)                |         |
| Duration of disease (day)                           | 21.0 (10.0–26.0)     | 21.0 (12.0–24.0)        | 0.929*  |
| Mini mental state examination                       | 21.0 (20.0–27.0)     | 26.0 (24.0–29.0)        | 0.249*  |
| Somatosensory evoked potential                      |                      |                         | 1<sup>st</sup> |
| Normal                                              | 7 (77.8)             | 6 (66.7)                |         |
| Abnormal                                            | 2 (22.2)             | 3 (33.3)                |         |
| Strength of knee extensor (manual muscle test)      | 3.0 (3.0–4.0)        | 4.0 (2.0–5.0)           | 0.492*  |
| Spasticity of ankle plantar flexor (modified Ashworth Scale) | 1.0 (1.0–1.0)     | 1.0 (1.0–1.0)           | 1<sup>st</sup> |
| Korean version of Berg Balance Scale                | 3.0 (1.0–5.0)        | 5.0 (3.0–12.0)          | 0.131<sup>st</sup> |
| Functional Ambulation Category                      | 1.0 (1.0–2.0)        | 2.0 (1.0–2.0)           | 0.206<sup>st</sup> |
| Korean version of modified Barthel Index            |                      |                         | 1<sup>st</sup> |
| Total                                               | 31.0 (27.0–52.0)     | 45.0 (33.0–55.0)        | 0.310<sup>st</sup> |
| Self-care                                           | 14.0 (7.0–19.0)      | 14.0 (12.0–19.0)        | 0.689<sup>st</sup> |
| Mobility                                            | 0.0 (0.0–3.0)        | 3.0 (0.0–3.0)           | 0.591<sup>st</sup> |

Values are presented as median (interquartile range) or frequency (%). WBV, whole-body vibration.
<sup>a</sup>Calculated by Mann-Whitney U-test. <sup>b</sup>Calculated by Fisher’s exact test.

### Table 2. Comparison of muscular strength and functional performance per group

| Variable                                      | Whole-body vibration (N = 9) | Control (N = 9) | P-value<sup>st</sup> |
|-----------------------------------------------|------------------------------|-----------------|----------------------|
| Strength of lower extremity                   | 3.0 (3.0–4.0)                | 4.0 (3.0–5.0)   | 0.071                |
| Spasticity of lower extremity                 | 1.0 (1.0–1.0)                | 1.0 (1.0–1.0)   | 0.346                |
| Korean version of Berg Balance Scale          | 3.0 (1.0–5.0)                | 5.0 (3.0–12.0)  | 0.009                |
| Functional Ambulation Category                | 1.0 (1.0–2.0)                | 2.0 (1.0–2.0)   | 0.008                |
| K-MBI                                         | 31.0 (27.0–52.0)             | 45.0 (33.0–55.0) | 0.004                |
| K-MBI subscore–self-care                      | 14.0 (7.0–19.0)              | 14.0 (12.0–19.0) | 0.009                |
| K-MBI subscore–mobility                       | 0.0 (0.0–3.0)                | 3.0 (0.0–3.0)   | 0.009                |

Values are presented as median (interquartile range). Bold type is considered statistically significant.
K-MBI, Korean version of Modified Barthel Index.
<sup>a</sup>Calculated by Wilcoxon’s signed rank test. <sup>st</sup>Calculated by Mann-Whitney U-test for comparing the gap of before and after intervention between two groups.
The difference of BBS between pre-WBV intervention and post-WBV intervention is significant in the WBV group as compared to the control group by Mann-Whitney U-test ($P = 0.037$). WBV, whole-body vibration; BBS, Berg Balance Scale.

**Fig. 3.** Comparison of Berg Balance Scale between both groups. The difference of BBS between pre-WBV intervention and post-WBV intervention is significant in the WBV group as compared to the control group by Mann-Whitney U-test ($P = 0.037$). WBV, whole-body vibration; BBS, Berg Balance Scale.

3. The paretic knee extensor strength

The MMT score of the paretic knee extensor strength in the WBV group showed the tendency to differ after the WBV intervention, but it did not reveal a statistical significance, from 3.0 (3.0–4.0) to 4.0 (3.0–5.0) ($P = 0.071$).

4. The paretic ankle plantar flexor spasticity

The MAS score differences in the paretic ankle plantar flexor spasticity were not significant in both the groups at post-intervention. The WBV intervention did not affect the change of the muscle spasticity.

5. The walking ability

After a 4-week intervention, the difference of the FAC score was statistically significant in the both groups, from 1.0 (1.0–2.0) to 4.0 (3.0–5.0) for the WBV group ($P < 0.05$) and from 2.0 (1.0–2.0) to 3.0 (2.0–4.0) for the control group ($P < 0.05$). Furthermore, the difference in the FAC scores of the WBV group was significantly larger as compared to the control group, 2.0 (2.0–3.0) for the WBV group and 1.0 (1.0–1.0) for the control group ($P < 0.05$).

6. Activities of daily living

The difference of the total MBI scores before and after intervention was significant in the both groups, from 31.0 (27.0–52.0) to 79.0 (46.0–85.0) for the WBV group ($P < 0.05$) and from 45.0 (33.0–55.0) to 66.0 (44.0–67.0) for the control group ($P < 0.05$). Furthermore, the difference in the total MBI scores of the WBV group was significantly larger as compared to the control group, 31.0 (21.0–40.0) for the WBV group and 16.0 (8.0–19.0) for the control group ($P < 0.05$).

The difference of the self-care MBI scores before and after the intervention was significant in the both groups, from 14.0 (7.0–19.0) to 29.0 (17.0–33.0) for the WBV group ($P < 0.05$) and from 14.0 (12.0–19.0) to 23.0 (17.0–25.0) for the control group ($P < 0.05$). However, the difference in the self-care MBI scores between the both groups was not significant.

The difference of the mobility MBI scores before and after the intervention was significant in the both groups, from 0.0 (0.0–3.0) to 14.0 (5.0–20.0) for the WBV group ($P < 0.05$) and from 3.0 (0.0–3.0) to 5.0 (3.0–10.0) for the control group ($P < 0.05$). Furthermore, the difference in the mobility MBI scores of the WBV group was significantly larger as compared to the control group, 10.0 (5.0–14.0) for the WBV group and 3.0 (2.0–7.0) for the control group ($P < 0.05$).

7. The correlation between the Berg Balance Scale and the functional outcomes (Functional Ambulation Category, Modified Barthel Index)

After 4-week intervention, the relationship between the difference of the BBS scores and FAC and MBI scores (total, self-care, mobility) was examined using Spearman’s rank correlation. The difference of the BBS scores showed a significantly positive correlation with the difference of the FAC scores ($r = 0.82, P < 0.001$) (Table 3), total MBI scores ($r = 0.58, P < 0.05$), self-care MBI ($r = 0.54, P < 0.05$), and mobility MBI ($r = 0.85, P < 0.001$). The differ-
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DISCUSSION

The main findings of the present study were: (1) subacute stroke patients with severe functional impairments showed more effective improvements in balance and gait performance after 4 weeks of WBV intervention than patients not subjected to the WBV intervention, and (2) differences in BBS scores was more associated with mobility MBI scores than with self-care MBI scores.

Two types of WBV have been developed: vertical WBV (synchronous and side-alternating vibrations) [28] and horizontal WBV [29]. The Galileo Med S equipment used in the present study is a side-alternating vibration device. Side-alternating vibration presents three characteristics. First, the platform rotates around an anteroposterior horizontal axis, and a greater distance from the axis of rotation to the point of application results in vibrations of larger amplitudes [30]. Second, the device evokes rotational movements around the hip and the lumbosacral joints that introduce an additional degree of freedom to the therapy. Consequently, a side-alternating WBV presents lower whole-body mechanical impedance than synchronous WBV and can be expected to reduce the vibration transmission to the trunk and head [10]. Finally, the electromyography (EMG) activity on recorded lower limb muscles has been observed to be significantly greater during side-alternating vibration than during synchronous vibration. The combination of high vibration frequencies of 30 Hz and an additional loading onto a side-alternating vibration platform is associated with maximum EMG activity during the WBV exposure. Therefore, side-alternating WBV is assumed to be the most efficient for WBV training purposes [31].

The frequency range of vibration stimulation used in this study

Table 4. Correlation between MBI and BBS (n = 18)

| Variable                  | Correlation coefficient | P-value |
|---------------------------|-------------------------|---------|
| MBI (total)               |                         |         |
| Pre-MBI and pre-BBS       | 0.80                    | < 0.001 |
| Post-MBI and post-BBS     | 0.90                    | < 0.001 |
| ΔMBI and ΔBBS             | 0.58                    | 0.011   |
| MBI (self-care)           |                         |         |
| Pre-MBI and pre-BBS       | 0.65                    | 0.003   |
| Post-MBI and post-BBS     | 0.84                    | < 0.001 |
| ΔMBI and ΔBBS             | 0.54                    | 0.021   |
| MBI (mobility)            |                         |         |
| Pre-MBI and pre-BBS       | 0.67                    | 0.003   |
| Post-MBI and post-BBS     | 0.86                    | < 0.001 |
| ΔMBI and ΔBBS             | 0.85                    | < 0.001 |

Correlation coefficients were computed by Spearman’s rank correlation. Bold types represent significant differences.

MBI, Modified Barthel Index; BBS, Berg Balance Scale.

Fig. 4. Comparison of total MBI (A), self-care MBI (B), and mobility MBI (C) between both groups. The difference of total MBI scores and mobility between pre-WBV intervention and post-WBV intervention is significant in the WBV group as compared to the control group by Mann-Whitney U-test (P < 0.06). WBV, whole-body vibration; MBI, Modified Barthel Index. *P < 0.05.
has been reported to be therapeutic by previous studies [12, 32]. Vibrations at a frequency below 20 Hz were not used in this study because they may induce a considerable resonance effect, resulting in amplification of the vibration stimulation and increased risk of adverse effects, including damage to the internal organs [33]. Frequencies higher than 30 Hz were also not used in our experiment because of the associated higher peak acceleration values [34]. The WBV amplitude was established as such because this value has been reported to bring about improvement in the balance and health-related quality of life in healthy subjects and nursing home residents [12, 35].

Contrary to the result shown in the present study, several studies have reported that WBV therapy is ineffective in improving balance in patients after a stroke. Van Nes et al. [27] reported that although daily sessions of WBV for 6 weeks improved balance, this improvement was not more effective than that observed in the control group who received the same amount of exercise therapy. However, because the study did not state the exact intensity of exercise therapy, comparing the effects of exercise with those of WBV training may be difficult. The participants in the control group in our study performed the same type of static standing exercise as those in the WBV group but were not exposed to the vibration stimuli; thus, we could clearly delineate the effects of a WBV intervention. Also, the intensity of the WBV intervention in the present study was higher than in that study. Another study showed that 8-week WBV therapy 3 times a week was no more effective in improving balance performance in patients with a chronic stroke with mild to moderate motor impairments [36]. Unlike in this study, however, the participants in the present study were patients with subacute stroke and severe functional impairments; therefore, they may receive more beneficial effects from WBV intervention. Our findings concur with those of previous studies showing that WBV therapy exerts superior therapeutic effects in highly compromised population [37, 38].

We supposed two mechanisms to explain our observation of balance recovery after WBV intervention: an increase in proprioception and improvement of weight bearing to the affected side. Tankisheva et al. [15] suggested that improvement in postural control after WBV training may be related to improvements in paretic knee muscle strength and proprioception. Vibrations are believed to bring about intense and deep stimulation of muscle afferent pathways and improve postural control in patients with stroke [38, 39]. In particular, WBV can mainly stimulate the Ia afferent pathways of the muscle, thereby increasing proprioceptive sensory input and inducing sensory system-mediated postural control [39]. In the present study, patients in the WBV group showed significantly improved BBS scores but not paretic knee extensor muscle strength. Therefore, the main mechanism for balance recovery in subacute stroke patients in this study may be an increment of proprioceptive sensory input.

Several researchers have suggested that improvements in weight shifting or weight bearing to the paretic side are associated with balance recovery. Van Nes et al. [14] assumed that increases in proprioceptive input by WBV were related to improvement in weight-shifting in chronic stroke patients. Another study reported that 6 weeks of WBV training with horizontal vibrations at a frequency of 1–3 Hz and an amplitude of 30 mm brought about sensory stimulation to the bilateral sides and enabled weight bearing in either the anteroposterior or the bilateral direction, thus improving balance in patients with chronic stroke [29]. Chan et al. [17] demonstrated that WBV caused significantly different changes in body weight loading on each foot in patients with chronic stroke. After vibration therapy, the proportion of total body weight loading significantly increased on the paretic side and significantly decreased on the non-paretic side; this finding suggests that patients shifted their body weight from the non-paretic side to the paretic side during static standing.

Balance recovery was shown to exert a greater influence on the improvement in the gait performance in the WBV group than in the non-WBV group. Huh et al. [40] reported that balance control training improved both balance and gait, but not paretic knee extensor strength in subacute hemiplegic stroke patients. The results of the present study showed that, despite the absence of change in both the ankle plantar flexor spasticity and paretic knee extensor strength, WBV intervention induced significant improvement in walking ability; improvements in gait capacity were also deeply associated with improvement in balance control. Given these two findings, WBV stimulation appears to increase weight-shifting to the paretic side and improve balance control, thereby efficiently improving gait performance, during early stage of stroke rehabilitation.

This study showed that balance recovery through WBV intervention is related to improvement in the ADL performance of subacute stroke patients. In particular, the change in BBS scores was more correlated with improvements in mobility MBI scores than with improvement in self-care MBI scores. Although the change
in self-care MBI scores was moderately associated with a change in BBS scores, differences in self-care MBI scores in the WBV group and non-WBV group after 4 weeks of intervention were not significant. By contrast, mobility MBI score significantly differed in the WBV group in comparison with those in the non-WBV group after 4 weeks of intervention. Changes in BBS scores also showed a similar degree of correlation with changes in FAC and mobility MBI scores. WBV intervention may improve trunk control and prevent low cardiovascular fitness, which positively influences mobility and ambulation [3]. Further studies are necessary to investigate the precise effects of WBV intervention on the trunk control and recovery of cardiovascular fitness.

Although WBV training appears to improve lower limb muscle strength, the potential advantages of this therapy over traditional forms of static standing exercise remain unclear. In the present study, the paretic knee extensor strength of subacute stroke patients did not significantly change after 4 weeks WBV intervention compared with that of the non-WBV group. Two factors may explain this finding: the participant’s posture during WBV intervention and relatively short duration of WBV intervention. A study has suggested that a knee flexion of 60° and a normal stance with the heels in contact with the platform is the most beneficial conditions for the strengthening the paretic knee extensor muscle [31]. However, participants in the WBV group in the present study could not maintain the suggested posture because of weak lower limb power and poor standing balance. Instead, with the support of a buttock belt, they maintained a standing posture with a slight knee flexion less than 60° during WBV intervention. We also selected a 4-week WBV intervention comparable with a previous study showing the beneficial effects of WBV in patients after acute stroke [32]. However, because a WBV training interval of at least 6 weeks is recommended to achieve a significant gain in muscle strength [10], the 4-week WBV intervention period applied in this work may be inadequate to improve paretic knee extensor strength.

We measured the spasticity of the paretic ankle plantar flexor but not that of the paretic knee extensor on the basis of the previous studies showing that the change in the former are highly related to improvements in ambulation [17], while changes in the latter are not [41]. In this study, the effect of WBV on changes in paretic ankle plantar flexor spasticity were not significant. This result may be attributed to the following two factors. First, as the degree of participants’ spasticity was absent or mild (MAS, 0–1) pre-intervention, noticeable improvements in spasticity after WBV intervention are not likely. Second, the MAS itself may limit our observations. The MAS does not provide a valid measure of spasticity at lower grades [42]; therefore, it may not be able to differentiate between patients with very mild spasticity and those without. To grade mild spasticity, the MAS could be replaced by a quantitative evaluation, such as the Hmax/Mmax ratio [43]. A previous study showed that both the MAS score of paretic ankle spasticity and the Hmax/Mmax ratio significantly decreased in the WBV group compared with those in the control group [17].

In the present study, none of the groups reported adverse effects or uncomfortable symptoms, in contrast to previous reports [19,27,42], despite the participants’ advanced age and severe functional impairments. The risk of adverse health effects may decreased by applying side-alternating WBV rather than synchronous WBV and by requiring semi-squats rather than full-squats or an upright stance [10,30]. As well, the intensity of vibration stimuli should be controlled to reduce side effects [44].

1. The limitations of this study

The results of the present study should be carefully interpreted because this study presents limitations. First, the relatively small sample size may influence the statistical significance of the variables. Second, the effect of the WBV on the functional recovery was not determined according to the lesion or type of stroke. Further studies will require a larger sample size in order to more definitely investigate the effect of WBV on the neurological recovery according to the lesion and type of stroke. Finally, the participants in the control group were not completely blinded to the group allocation because they could not feel vibration on the WBV platform during the standing exercise.

2. Conclusion

The present study suggests that daily inclusion of WBV intervention to conventional stroke rehabilitation could effectively recover balance control and improve the mobility and gait performance of subacute stroke patients with severe functional impairments.

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