Relationship between walking ability of patients with stroke and effect of body weight-supported treadmill training

Hikaru Mori, RPT, MS1)*, Makoto Tamari, RPT, PhD2), Hitoshi Maruyama, RPT, PhD3)

1) Kinki Rehabilitation College: 3-3-2 Mishima, Settsu City, Osaka 566-0022, Japan
2) Fukuoka International University of Health and Welfare, Japan
3) Graduate School, International University of Health and Welfare, Japan

Abstract. [Purpose] Reports on the amount of unloading maximizing walking ability in patients with stroke are limited. The effect of body weight-supported treadmill training (BWSTT) in patients with stroke has not been clarified. We aimed to investigate the effects of unloading rate during BWSTT on the gait of patients with stroke and the relationship between BWSTT and walking ability on flat ground. [Participants and Methods] We performed BWSTT in 17 patients at three unloading rates: 0%, 20%, and 40%. Then, we examined the walking speed and rate, number of steps, single-leg support time ratio, and root mean square before and after unloading. Furthermore, we examined the relationship between walking ability on flat ground and immediate effects of BWSTT at each unloading rate. [Results] We observed no significant improvement under all conditions. However, walking ability improved at unloading rates of 20% and 40%, with poor temporal symmetry while walking on flat ground. [Conclusion] Our results revealed that BWSTT has diverse effects depending on the unloading rate and the ability to walk on flat ground. In particular, it tends to be highly effective for those who have poor sway and symmetry, which may serve as an index for prescribing BWSTT.

Key words: Stroke, Body weight support treadmill training, Triaxial accelerometer

INTRODUCTION

One intervention approach to gait disturbance after stroke is body weight-supported treadmill training (BWSTT), which involves walking on a treadmill while the body is pulled upward by a harness. Advantages of BWSTT include being able to start walking practice early after the onset of stroke with the assistance of a harness1), enabling long distance walking2), and improving physical endurance, all while ensuring safety during activity. It is also expected to improve the left-right asymmetric gait by suppressing the compensatory movement on the non-paralyzed side through reduction of the burden on the paralyzed lower limb3). However, there are reports that the effect varies depending on the degree of independence during walking4) and that there is no significant difference between BWSTT and walking exercise without weight support5-7); furthermore, it is not clear whether it is effective. Many of these reports have verified the effects of walking speed and number of steps but not those of walking indices related to walking independence, such as sway and symmetry, and the setting of the unloading rate has not been unified, which is considered a factor whose effectiveness has not been clarified.

Therefore, the purpose of this study was to clarify the characteristics of patients for whom this treatment was effective by verifying whether the effects of BWSTT differ depending on walking ability, by adding indicators of sway and symmetry.

*Corresponding author. Hikaru Mori (E-mail: mori@kinki-reha.com)
©2020 The Society of Physical Therapy Science. Published by IPEC Inc.
This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial No Derivatives (by-nc-nd) License. (CC-BY-NC-ND 4.0: https://creativecommons.org/licenses/by-nc-nd/4.0/)
Participants included 17 patients with hemiplegic stroke with independent walking (Table 1). We excluded those with higher brain function and cognitive impairment.

The BWSTT protocol employed a weight-bearing device (Unweighing System; Biodex, NY, USA) and a treadmill (T650MS; SportsArt, Tainan City, Taiwan). Unloading was applied at three rates as follows: 0%, 20%, and 40%. The order of unloading amount was determined randomly. The enforcement time was set to 15 using the Borg Scale, which subjectively measures participant fatigue. Treadmill speed was set at the fastest walking pace that could be accomplished with a constant gait and was judged by multiple physical therapists. To minimize the effects of fatigue, one unloading condition was performed each day for 3 days.

The 10-m walking test was conducted on a flat ground with 2-m spare roads before and after, and the maximum walking speed, number of steps, and walking rate during comfortable walking were calculated. A three-axis accelerometer (LegLog; Bisen, JPN) was attached near the spinous process of the third lumbar spine, and trunk accelerations in the left-right, vertical, and front-back directions during walking were measured every 5 msec. The use of daily walking sticks and short leg braces was permitted. Acceleration data was calibrated with the included analytical instrument (LegLog; Bisen, JPN); after visually confirming that the waveform was in a steady state, heel contact was determined according to a previous research (8), and the

was permitted. Acceleration data was calibrated with the included analytical instrument (LegLog; Bisen, JPN); after visually confirming that the waveform was in a steady state, heel contact was determined according to a previous research (8), and the

The central five walking cycles were analyzed. Next, we calculated the ratio of single-leg support time by dividing the paralysis single-leg support time by the non-paralysis-side single-leg support time as an index to express temporal symmetry, and the root mean square (RMS) was used as an index to express sway. RMS in trunk acceleration is affected by walking speed and is proportional to the square of walking speed (9), so we performed adjustments by dividing by the square value of walking speed.

For statistical analysis, we confirmed the normality of the extracted data using the Shapiro-Wilk test and used parametric and nonparametric tests accordingly. We used the SPSS14.0 J software for analysis. We set the significance level at 5%. For each unloading condition, we compared the walking speed before and after BWSTT and walking rate using the corresponding t-test. We compared the number of steps, single-leg support time ratio, and RMS using the Mann-Whitney U test. In addition, we used Spearman’s rank correlation coefficient to determine the relationship between walking ability on flat ground and the immediate effect of BWSTT. In addition, walking ability on flat ground was determined for the patients as the value obtained on the first day of measurement before undergoing BWSTT.

We explained the purpose and method of the study verbally and in written form to all participants and obtained consent from them before commencing the study. This study was approved by the ethics review board of the International University of Health and Welfare (approval number: 15-Ith-43).

### RESULTS

In comparing walking ability before and after BWSTT, no significant change was observed in all indicators under all unloading conditions (0%, 20%, and 40%) (Table 2).

In the 0% unloading condition, there was no significant correlation between almost all indicators of flat-ground walking ability and those immediately after, while the 20% and 40% conditions showed single-leg support time in flat-land walking ability and immediate effects after BWSTT. There was a significant correlation with all indices (0.47<\(r\)0.87, p<0.01). In addition, there was a significant correlation between RMS in flat ground walking and single leg support time ratio immediately after the trial (0.32<\(r\)0.56, p<0.05). In the 40% condition, there was a significant correlation between the RMS during flat-ground walking ability and that in all directions immediately after the trial (0.43<\(r\)0.65, p<0.05). There was a significant correlation between RMS in the left-right and front-back directions immediately after the trial (0.48<\(r\)0.57, p<0.01) (Tables 3–5).

### DISCUSSION

We examined the effects of BWSTT on the walking ability of patients with stroke, not only on walking speed, number of steps, and walking rate, which were conventionally used, but also on left-right symmetry and sway ability using a triaxial accelerometer. Additionally, to verify the effect of BWSTT, different unloading rates were studied. As a result, the immediate effect of BWSTT was not observed at the unloading rate of 0%, 20%, or 40%. However, the immediate effect at 20% and 40% was related to sway ability and temporal symmetry in walking on flat ground.
In a report analyzing gait on a treadmill\(^{10}\), the stance phase time of the lower limb on the paralyzed side was extended at an unloading rate of 15% and further extended at 30%. However, there was no significant change in walking ability before and after BWSTT with all unloading rates. Barbeau\(^{11}\) reported that those who had improved walking ability with BWSTT were those with a walking speed of <0.2 m/sec before physical therapy and those with a walking endurance of <20 m. This suggests that BWSTT is likely to be effective for people with low walking ability. In the present study, because there was

### Table 2. Comparison of walking index before and after BWSTT

|                        | 0%     | 20%    | 40%    |
|------------------------|--------|--------|--------|
| Walking speed (m/sec)  | Before | After  | Before | After  | Before | After  |
|                        | 0.79 ± 0.49 | 0.82 ± 0.31 | 0.83 ± 0.31 | 0.86 ± 0.37 | 0.86 ± 0.36 | 0.89 ± 0.38 |
| Steps                  | 21.29 ± 5.21 | 20.53 ± 4.74 | 20.94 ± 5.47 | 20.06 ± 5.90 | 20.82 ± 5.43 | 20.71 ± 5.80 |
| Walking rate (steps/sec)| 1.57 ± 0.27 | 1.60 ± 0.29 | 1.58 ± 0.30 | 1.58 ± 0.29 | 1.65 ± 0.31 | 1.67 ± 0.30 |
| Ratio of single-leg support time | 0.84 ± 0.09 | 0.89 ± 0.11 | 0.86 ± 0.11 | 0.81 ± 0.21 | 0.78 ± 0.12 | 0.83 ± 0.18 |
| RMS Front-back direction | 3.82 ± 2.56 | 3.56 ± 1.99 | 3.77 ± 2.73 | 3.82 ± 2.43 | 3.58 ± 2.66 | 3.70 ± 2.69 |
| RMS Horizontal direction | 4.19 ± 2.08 | 4.12 ± 2.01 | 3.79 ± 2.28 | 3.96 ± 2.04 | 3.63 ± 2.06 | 3.99 ± 2.78 |
| RMS Vertical direction  | 3.90 ± 2.42 | 3.77 ± 2.11 | 3.91 ± 2.60 | 4.06 ± 2.41 | 3.75 ± 2.57 | 3.80 ± 2.55 |

Mean ± SD. RMS: root mean square; n.s: not significant; BWSTT: body-weight supported treadmill training.

### Table 3. Relationship between walking ability on flat ground at 0% unloading rate and effect of BWSTT

| BWSTT effects | Walking ability on flat ground |
|---------------|-------------------------------|
|               | Walk speed | Steps | Walking rate | Ratio of single-leg support time | Left-right | Vertical | Front-back |
| Walk speed    | −0.16      | 0.13  | 0.17         | −0.34*                       | 0.17       | 0.16     | 0.21       |
| Steps         | 0.27       | −0.28 | 0.25         | −0.30*                       | −0.33      | −0.34    | −0.38      |
| Walking rate  | 0.18       | −0.18 | 0.29         | 0.19                         | −0.27      | −0.27    | −0.26      |
| Ratio of single-leg support time | −0.12       | −0.21 | −0.08        | −0.11                       | 0.13       | −0.16    | 0.21       |
| RMS           | Left-right | 0.35  | −0.33 | 0.17         | 0.12         | −0.27 | −0.19 | −0.45* |
| Vertical      | −0.09      | 0.18  | −0.02        | −0.21                       | 0.21       | −0.09    | 0.33       |
| Front back    | 0.25       | −0.38 | 0.31         | 0.08                        | −0.39      | −0.38    | −0.37      |

BWSTT: Body Weight Supported Treadmill Training; RMS: root mean square. *p<0.05, **p<0.01.

### Table 4. Relationship between walking ability on flat ground at 20% unloading rate and effect of BWSTT

| BWSTT effects | Walking ability on flat ground |
|---------------|-------------------------------|
|               | Walk speed | Steps | Walking rate | Ratio of single-leg support time | Left-right | Vertical | Front-back |
| Walk speed    | 0.02       | −0.07 | 0.47*        | −0.67**                      | −0.03      | −0.07    | 0.12       |
| Steps         | −0.05      | 0.18  | 0.06         | −0.55**                      | 0.13       | 0.17     | −0.08      |
| Walking rate  | −0.01      | 0.12  | 0.21         | −0.56**                      | 0.05       | 0.05     | 0.11       |
| Ratio of single-leg support time | −0.44       | 0.31  | −0.09        | −0.80**                      | 0.43**     | −0.40**  | −0.32**     |
| RMS           | Left-right | 0.26  | −0.27        | −0.71**                      | −0.64**    | 0.23     | 0.14       |
| Vertical      | −0.42*     | 0.57**| −0.66**      | −0.68**                      | 0.31       | 0.31     | 0.32       |
| Front back    | 0.27       | −0.21 | −0.55**      | −0.47**                      | −0.18      | −0.21    | −0.29      |

### Table 5. Relationship between walking ability on flat ground at 40% unloading rate and effect of BWSTT

| BWSTT effects | Walking ability on flat ground |
|---------------|-------------------------------|
|               | Walk speed | Steps | Walking rate | Ratio of single-leg support time | Left-right | Vertical | Front-back |
| Walk speed    | −0.26      | 0.29  | −0.44**      | −0.68**                      | 0.66**     | 0.09     | 0.50       |
| Steps         | −0.24      | 0.37  | −0.17        | −0.87**                      | 0.18       | 0.17     | 0.18       |
| Walking rate  | −0.05      | 0.06  | 0.00         | −0.81**                      | −0.03      | −0.14    | 0.03       |
| Ratio of single-leg support time | −0.34       | 0.23  | −0.14        | −0.66**                      | 0.56**     | −0.44**  | −0.34**     |
| RMS           | Left-right | 0.32  | −0.47**      | −0.61**                      | 0.59**     | −0.10    | −0.57**     |
| Vertical      | 0.30       | −0.32 | −0.54**      | −0.81**                      | 0.65**     | −0.30    | −0.15       |
| Front back    | 0.33       | −0.36 | −0.49**      | −0.55**                      | 0.43*      | −0.34    | −0.48**     |

BWSTT: Body Weight Supported Treadmill Training; RMS: root mean square. *p<0.05, **p<0.01.
no restriction other than the degree of independence in the walking ability of the participants, immediate effects may vary depending on the participant’s walking ability. Furthermore, there may be no significant difference in walking ability. Therefore, we examined the potential relationship between walking ability on flat ground and the immediate effects on walking ability after BWSTT. As a result, in the 20% and 40% unloaded conditions, improvement in walking speed, number of steps, walking rate, and symmetry was greater for those who walked on flat ground and had poor symmetry and sway. In addition, 40% of the unloading group showed significant improvement in lateral mobility. Based on this, we can infer that the effect of BWSTT is related not only to the amount of unloading but also to the participant’s ability to walk on flat ground. Temporal symmetry can be an indicator of the immediate effects after BWSTT independent of walking speed and number of steps.

Regarding the immediate effect of BWSTT, walking speed and number of steps have been frequently studied; however, in this study, only the relationship between unloading rate, swayability, and temporal symmetry was recognized. In previous studies, the effectiveness of BWSTT could be attributed to sway and symmetry. In future studies, verifying the effects on walking ability by conducting verifications that consider these indicators in addition to unloading rate should be conducted.

This study had some limitations. We used a cross-sectional methodology; thus, it was not possible to analyze factors related to the effect of BWSTT. In future studies, the setting and characteristics of participants should be subdivided using factor analysis with multifaceted walking indices.

In conclusion, BWSTT may improve poor mobility and temporal symmetry if the unloading rate is increased. When investigating the effects of BWSTT, it is necessary to consider not only the walking speed and number of steps but also mobility and temporal symmetry.

Clarifying a setting that maximizes the effect of BWSTT is important because this could optimize rehabilitation for patients with stroke. In the future, we will examine differences based on the degree of shaking and temporal symmetry.

**Funding**

No funding sources need disclosing.

**Conflict of interest**

There are no conflicts of interest to declare.

**REFERENCES**

1) Hasegawa T, Uchiyama S: Global standard of BWSTT. Rigakuryohougaku, 2013, 40: 578–579 (in Japanese).
2) Peurala SH, Tarkka JM, Pitkänen K, et al.: The effectiveness of body weight-supported gait training and floor walking in patients with chronic stroke. Arch Phys Med Rehabil, 2005, 86: 1557–1564. [Medline] [CrossRef]
3) Takei K, Kaneko S, Kunisawa Y, et al.: Characteristics of body weight supported treadmill training for post-stroke hemiparetic subject in recovery stage: comparison of the change in walking speed, walking distance, gait pattern between different walking training. Rigakuryohougaku, 2010, 37: 139–145 (in Japanese).
4) Mehrholz J, Pohl M, Eilsner B: Treadmill training and body weight support for walking after stroke. Cochrane Database Syst Rev, 2014, 23: CD002840. [Medline] [CrossRef]
5) Kosak MC, Reding MJ: Comparison of partial body weight-supported treadmill gait training versus aggressive bracing assisted walking post stroke. Neurorehabil Neural Repair, 2000, 14: 13–19. [Medline] [CrossRef]
6) Nilsson L, Carlsson J, Danielsson A, et al.: Walking training of patients with hemiparesis at an early stage after stroke: a comparison of walking training on a treadmill with body weight support and walking training on the ground. Clin Rehabil, 2001, 15: 515–527. [Medline] [CrossRef]
7) da Cunha FT Jr, Lim PA, Qureshy H, et al.: Gait outcomes after acute stroke rehabilitation with supported treadmill ambulation training: a randomized controlled pilot study. Arch Phys Med Rehabil, 2002, 83: 1258–1265. [Medline] [CrossRef]
8) Auvinet B, Berrut G, Touzard C, et al.: Reference data for normal subjects obtained with an accelerometric device. Gait Posture, 2002, 16: 124–134. [Medline] [CrossRef]
9) Menz HB, Lord SR, Fitzpatrick RC: Acceleration patterns of the head and pelvis when walking on level and irregular surfaces. Gait Posture, 2003, 18: 35–46. [Medline] [CrossRef]
10) Hesse S, Konrad M, Uhlenbrock D: Treadmill walking with partial body weight support versus floor walking in hemiparetic subjects. Arch Phys Med Rehabil, 1999, 80: 421–427. [Medline] [CrossRef]
11) Barbeau H, Vissintin M: Optimal outcomes obtained with body-weight support combined with treadmill training in stroke subjects. Arch Phys Med Rehabil, 2003, 84: 1458–1465. [Medline] [CrossRef]