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Original Article

Recovery Process of Standing Postural Control in Hemiplegia after Stroke

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Abstract. [Purpose] The aim of this study was to investigate the recovery process of standing postural control in hemiplegia after stroke. [Subjects and Methods] Thirty-four inpatients with hemiparesis after first-onset stroke were included in this study. We measured the center of pressure fluctuations during quiet standing using a force platform at 2, 4, and 6 weeks after admission. We assessed weight-bearing asymmetry, and velocity and amplitude of body sway. [Results] Weight-bearing asymmetry diminished in the first 2 weeks of observation. Velocity of body sway also decreased significantly in the first 2 weeks, though its amplitude only decreased significantly after 4 weeks of observation. [Conclusion] Amplitude of body sway requires a longer time for significant improvement than weight-bearing asymmetry and velocity of body sway. Although the loading function of the paretic lower limb improved at an early stage, attainment of optimum postural control, including management of the affected paretic lower limb, requires much time.

Key words: Postural balance, Hemiplegia, Recovery of function

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INTRODUCTION

Postural control involves controlling the body's position in space for the dual purpose of stability and orientation. Postural orientation is defined as the ability to maintain an appropriate relationship between the body segments and between the body and the environment for a task. Postural stability, or balance, is the ability to maintain the body in equilibrium[1)]. Postural control is often impaired after stroke. We focused on postural control during quiet standing in this study. Quiet standing postures of hemiplegics after stroke are characterized by weight-bearing asymmetry with a shift in the mean position of the center of pressure (COP) toward the unaffected side[2)], and an increase of body sway compared to age-matched healthy controls[3, 4)]. Body sway has a negative correlation with gait velocity[5)] and is related to the risk of falling[6, 7)].

Stable quiet standing supposedly contributes to improved gait ability and the prevention of falls. Although many researchers have reported on the characteristics of standing postural control in hemiplegics after stroke, few articles have mentioned the recovery process. Therefore, we measured the COP fluctuations of hemiplegic stroke patients during quiet standing using a force platform at 2, 4, and 6 weeks after hospital admission. The subjects were patients who were admitted to the sub-acute rehabilitation ward at the Fujita Health University Nanakuri Sanatorium, where we perform intensive rehabilitation for improvement of paretic function and activities of daily living (ADL). The purpose of this study was to investigate the recovery process of quiet standing postural control during rehabilitation treatment.

SUBJECTS AND METHODS

Thirty-four inpatients with hemiplegia after first-onset stroke were included in this study. The subjects had the ability to maintain independent unsupported quiet standing for 60 seconds, but could not walk independently at 2 weeks after admission even with orthoses or parallel bars. Subjects who had cognitive or psychiatric problems that impaired their ability to follow instructions and those who had neuromuscular impairment before the onset of the stroke were excluded from the study. Subjects' characteristics at 2 weeks after admission are shown in Table 1. Brunnstrom recovery stage[8)] (BRS) of the lower extremities, the lower extremity position sense item of the Stroke Impairment Assessment Set[9, 10)] (SIAS), and motor subscore, cognitive subscore, and gait item score of the Functional Independence Measure[11)] (FIM) were assessed at 2, 4, and 6 weeks after admission and are shown in Table 2.

COP was measured using a force plate system (Twin-gravicoder G6100; ANIMA Corp.). Subjects stood with their arms at their trunk sides and with one foot on each of

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Table 1. Characteristics of subjects (N=34)

Age (mean ± SD)	59.8 ± 13.7 years
Time post-stroke (mean ± SD)	45.7 ± 13.6 days
Gender (number)	men (28) women (6)
Type of stroke (number)	infarction (16) hematoma (18)
Affected side (number)	left (17) right (17)

Table 2. Characteristics of impairment and disability

Weeks	BRS of L/E (number)
2	I:1 II:7 III:7 IV:11 V: 8 VI:0
4	I:0 II:4 III:8 IV:14 V:8 VI:0
6	I:0 II:3 III:6 IV:14 V:11 VI:0
	SIAS of L/E position sense (number)
2	0:4 1:9 2:10 3:11
4	0:3 1:10 2:10 3:11
6	0:2 1:10 2:11 3:11
	FIM motor total score (mean ± SD)
2	60.7 ± 10.8
4	68.6 ± 8.8
6	73.1 ± 7.5
	FIM cognitive total score (mean ± SD)
2	28.2 ± 6.7
4	29.3 ± 6.0
6	29.9 ± 5.7
	FIM of gait item (number)
2	1:0 2:1 3:4 4:16 5:13 6:0 7:0
4	1:0 2:0 3:1 4:6 5:25 6:2 7:0
6	1:0 2:0 3:0 4:0 5:25 6:8 7:1

the two force plates. The feet were positioned parallel and they were 10 cm apart medially. Subjects wore their own shoes, but did not put on orthoses. Subjects stood with their eyes open and looked at a target placed at eye level, 2 m away. After subjects had stabilized themselves on the force platform, COP trajectories were measured for 60 seconds at a sampling rate of 20 Hz. Measurements were carried out at 2, 4, and 6 weeks after admission, and progress over the 4 weeks of observation was evaluated.

Time series of COP were analyzed to define weight-bearing asymmetry, body sway, and frequency. We investigated mean position (MP) in the mediolateral (M/L) direction, mean velocity (MV) in the M/L and anteroposterior (A/P) directions, root mean square distance (RMSD) in the M/L and A/P directions, and power in the M/L and A/P directions based on frequency analysis.

The MP in the M/L direction is the mean value of the X axis increments of the COP time series data, [Equation (1)]. A positive value indicates the unaffected side and a negative value indicates the paretic side. The MP value in the M/L direction was used in order to evaluate weight-bearing asymmetry.

$$X_{MP} = \frac{1}{n}\sum_{i=1}^{n} Xi \quad (1)$$

The MV values in the M/L and A/P directions are ratios of total length (LNG) of COP to measurement time, [Equations (2) and (3)]. The LNG values in the M/L and A/P directions were defined as the sum of the incremental distances moved in the X and Y directions of the COP time series data.

$$X_{MV} = \sum_{i=1}^{n} |\Delta x\, i| / 60 \quad (2)$$

$$Y_{MV} = \sum_{i=1}^{n} |\Delta y\, i| / 60 \quad (3)$$

The RMSD values in the M/L and A/P directions were calculated using Equations (4) and (5). They are the root mean square values of the COP time series data displacements from the mean values of the respective directions. The MP value in the A/P direction was calculated in the same way as that of the M/L direction, [Equation (6)].

$$X_{RMSD} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - x_{MP})^2} \quad (4)$$

$$Y_{RMSD} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - y_{MP})^2} \quad (5)$$

$$Y_{MP} = \frac{1}{n}\sum_{i=1}^{n} Yi \quad (6)$$

The MV and RMSD values in the M/L and A/P directions were used in order to evaluate body sway. The International Society of Posturography recommends the use of 2 COP-based measures: MV and RMSD[12]. MV represents the velocity of body sway and the RMSD is representative of the amplitude of body sway. Because postural control strategies in the M/L and A/P directions are controlled by different mechanisms[13, 14], MV and RMSD were analyzed in both directions. In quiet standing, postural control in the M/L direction is dominated by a loading/unloading response under the control of the hip abductors/adductors, and the A/P direction is regulated by synergistic motor patterns of the ankle plantarflexion and dorsiflexion[15].

In addition, the improvement rates of MV and RMSD in the M/L and A/P directions over the 4 weeks period from 2 weeks post-admission were calculated using Equation. (7).

$$\text{Improvement rate} = \frac{\text{value at 2weeks} - \text{value at 6 weeks}}{\text{value at 2 weeks}} \times 100 \quad (7)$$

Frequency analysis was also performed to investigate the characteristics of body sway. Frequency analysis was performed by applying Fast Fourier Transforms to the time-series data and calculating the power spectrum. The international standard for evaluating the frequency interval of the power spectrum is 0.02–0.2 Hz, 0.2–2.0 Hz, and 2.0–10.0 Hz[12]. We used the power of each frequency band

Table 3. Changes in mean position, mean velocity and root mean square distance

Weeks	Mean position	Mean velocity		Root mean square distance	
	M/L direction	M/L direction	A/P direction	M/L direction	A/P direction
2	3.7 ± 2.3	1.78 ± 0.99	1.91 ± 0.80	0.86 ± 0.43	0.72 ± 0.21
4	2.6 ± 2.0**	1.37 ± 0.80**	1.62 ± 0.50**	0.75 ± 0.36	0.66 ± 0.17
6	2.7 ± 2.0*	1.15 ± 0.65**, †	1.49 ± 0.54**	0.63 ± 0.30**	0.60 ± 0.14**

**: p<0.01 between 2 and 4/6 weeks data, *: p<0.05 between 2 and 4/6 weeks data, †: p<0.05 between 4 and 6 weeks data

Table 4. Changes in power levels of each frequency band

Weeks	0.02–0.2 Hz		0.2–2 Hz		2–10 Hz	
	M/L direction	A/P direction	M/L direction	A/P direction	M/L direction	A/P direction
2	0.37 ± 0.39	0.26 ± 0.33	0.48 ± 0.67	0.27 ± 0.23	0.01 ± 0.02	0.01 ± 0.01
4	0.37 ± 0.48	0.22 ± 0.15	0.28 ± 0.44**	0.17 ± 0.11**	0.01 ± 0.02**	0.00 ± 0.00**
6	0.22 ± 0.30	0.17 ± 0.10	0.14 ± 0.17**, †	0.14 ± 0.08**, †	0.00 ± 0.00**, †	0.00 ± 0.00**

**: p<0.01 between 2 and 4/6 weeks data, †: p<0.05 between 4 and 6 weeks data

as a parameter.

Friedman's χ^2 test was used to examine the significance of differences in MP in the M/L direction, and MV and RMSD in the M/L and A/P directions of COP, among the three assessment times. When a significant change was found, the Bonferroni method was used as a post -hoc test to confirm the significance. The paired t-test was used to compare the improvement rates of MV and RMSD in the M/L and A/P directions. Significance was accepted for values of p less than 0.05. All statistical procedures were performed using SPSS version 19.0 (IBM Corp.).

RESULTS

Table 3 shows the mean and standard deviation of MP in the M/L direction, MV in the M/L and A/P directions, and RMSD in the M/L and A/P directions at each measurement time. MP in the M/L direction significantly shifted to the center from the unaffected side during the 4-week observation period ($p < 0.05$), and MP in the M/L direction was significantly shifted to the center from the unaffected side in the first 2 weeks of observation ($p < 0.01$), but did not improve thereafter.

MV in the M/L and A/P directions decreased significantly in the 4-week observation period ($p < 0.01$). Remarkably, the improvement rate in the M/L direction (40.2%) was significantly larger than that in the A/P direction (26.9%) ($p < 0.01$). MV in the M/L direction decreased significantly both in the first 2 weeks ($p < 0.01$), and also the second 2 weeks of observation ($p < 0.05$). MV in the A/P direction decreased significantly in the first 2 weeks of observation ($p < 0.01$), but did not significantly improve thereafter.

RMSD in the M/L and A/P directions decreased significantly in the 4-week observation period ($p < 0.01$). Remarkably, the improvement rate in the M/L direction (35.0%) was larger than that in the A/P direction (21.1%), but the difference was not significant. However, the differences in RMSD in the M/L and A/P directions were not significant in the first 2 weeks or the second 2 weeks of observation.

Table 4 shows the mean and standard deviation of the power levels of each frequency band at each measurement time. There were no significant differences in the power levels of the 0.02–0.2 Hz band in the M/L and A/P directions between any of the observation times. The power levels of the 0.2–2 Hz band in the M/L and A/P directions decreased significantly over the 4-week observation period ($p < 0.01$), as well as in the first 2 weeks ($p < 0.01$), and the second 2 weeks ($p < 0.05$). The power levels of the 2–10 Hz band in the M/L and A/P directions decreased significantly in the 4-week observation period ($p < 0.01$), and in the first 2 weeks ($p < 0.01$). In the second 2 weeks, the power level in the M/L direction decreased significantly ($p < 0.05$), but that in the A/P direction did not significantly different.

DISCUSSION

In this study, weight-bearing asymmetry diminished significantly and velocity and amplitude of body sway of post-stroke hemiplegic patients in the M/L and A/P directions decreased significantly in the 4-week period starting 2 weeks after hospital admission. In the improvement of body sway, the reduction in the M/L direction was larger than that in the A/P direction. De Haart et al.[16] followed 37 stroke inpatients during their rehabilitation starting from the time they were able to stand independently for at least 30 seconds, on average 10 weeks post-stroke, and then 2, 4, 8, and 12 weeks later. They reported that weight-bearing asymmetry diminished in the following 12 weeks, body sway in the M/L and A/P directions decreased gradually over the whole 12 weeks, and body sway in the M/L direction decreased significantly more than that in the A/P direction. The results of our present study support their findings.

Reduction of body sway in the M/L direction was larger than that in the A/P direction. Hemiplegia after stroke causes a large perturbation in body sway in the M/L direction compared to age-matched healthy controls[16]. In post-stroke hemiplegia, a shift in the mean position of COP toward the unaffected side can compensate for the A/P directional perturbation on the unaffected side, but cannot compensate for the M/L directional perturbation. In other words, postural control of the M/L direction is strongly affected by paralysis. Therefore, improvement in the M/L direction reflects improvement in paretic side functions arising from rehabilitation training.

This study focused on the recovery process of weight-bearing asymmetry and body sway. Our results show that weight-bearing asymmetry diminished in the first 2 weeks, but did not improve thereafter. De Haart et al.[16] also reported that weight-bearing asymmetry diminished in the first 4 weeks, but did not improve thereafter. In the present study, the loading function of the paretic lower limb improved and the paretic leg contributed to postural control in the first 2 weeks. Considering the findings of Hase that overload on the paretic side might cause overcompensation on the unaffected side[17], the optimum weight-bearing ratio should be the target of early stage rehabilitation after admission for stroke patients' independence in ADL.

In comparison with the study by De Haart et al.[16], which did not define the characteristics of the recovery process of body sway, this study showed that the velocity of body sway decreased significantly in the first 2 weeks of observation, whereas the amplitude decreased significantly over 4 weeks. The timing in improvement was different. The reason for early improvement of velocity of body sway may be explained by the results of frequency analysis. Body sway of a low frequency is associated with minimal effort and less stress for maintaining quiet standing balance[18], and the high frequency components of body sway reflect activity in response to activation of the graviceptive and proprioceptive loops[19]. Since a significant decrease was shown by the high frequency bands (power of 0.2–2, 2–10 Hz band) in the first 2 weeks of observation, sensory feedback from the unaffected side may have contributed to the early improvement of velocity of body sway. Late improvement of amplitude of body sway is possibly explained by age-related changes during quiet standing, since Abrahamova et al. reported that the most sensitive COP parameter for detecting balance change was RMSD, and RMSD reflects the time taken for integrated processing of sensory inputs[20]. When the proprioceptive information from the feet and ankles is artificially altered, normal subjects are compelled to rely more on other sensory (visual and vestibular) input[21]. However, hemiplegics, who often have visual, vestibular, and somatosensory disturbance[17], have difficulty in coordinating these inputs, and thus much time is required to improve RMSD by rehabilitation.

Despite numerous intervention studies aimed at improving standing postural control, no definitive conclusion on the best approach to facilitate the recovery of standing postural control of post-stroke hemiplegia patients has been arrived at[22, 23]. One reason for this is the lack of adequate assessment of standing postural control. A limitation of the present study was the assessment of only COP. There are many ways of assessing postural control including COP measurements, as used in this study, alignment research with kinematics, and assessment of functional improvement in the paretic lower limb using EMG.

In conclusion, the amplitude of body sway of post-stroke hemiplegic patients requires a longer time to show significant improvement than weight-bearing asymmetry and velocity of body sway. Although the loading on the paretic lower limb improves at an early stage, attainment of optimum postural control, including management of the affected paretic lower limb, requires much time. We should emphasize standing training for the paretic lower limb in accordance with improvement in paretic function to facilitate the recovery of standing postural control.

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