Comparison of gait recovery patterns according to the paralyzed side in stroke patients

An observational study based on a retrospective chart review (STROBE compliant)

Cheol-Hyun Kim, MD (KMD), PhD[a], Hongmin Chu, MD(KMD)[a], Geon-Hui Kang, MD(KMD), MS[b],
Kwang-Ho Kim, MD(KMD)[a], Young-Ung Lee, MD(KMD)[a], Hyeon-Seo Lim, MD(KMD)[a],
Kang-Keyng Sung, MD(KMD), PhD[a], Sangkwan Lee, MD(KMD), PhD[a,b,*]

Abstract

Gait rehabilitations have been abundantly performed for post-stroke patients, because gait is the most important factor for the return of post-stroke patients to daily life. However, conventional uniform gait rehabilitations tend to be tedious and reduce motivation. The aim of this study was to contribute to the development of personalized rehabilitation of gait by identifying differences in gait recovery pattern according to the paralyzed side of post-stroke patients.

The gait analysis was performed on stroke patients who are right-handed and can walk independently. We retrospectively analyzed the results of pelvic movements and displacement of center of pressure (COP) during gait using corresponding equipments. To show the difference of gait recovery pattern according to the paralyzed side, we divided subjects into two groups, right (n = 19) and left (n = 20) hemiparesis group. The measured variables were as follows: tilt, obliquity, and rotation symmetries of pelvis; area, velocity, and lateral symmetry of COP.

First, in the left hemiparesis group, obliquity ($P < .01$) and rotation ($P < .01$) symmetries of the movement of the pelvis were significantly improved in the follow-up compared to the initial gait analysis. In the right hemiparesis group, tilt ($P < .001$), obliquity ($P < .001$), and rotation ($P < .05$) symmetries were significantly improved in the follow-up compared to the initial gait analysis. Second, COP area and COP velocity values in the follow-up were significantly smaller than those in the initial gait analysis in the left ($P < .001$, $P < .05$) and right ($P < .001$, $P < .01$) hemiparesis groups. The positive value of lateral symmetry increased, although not a significant difference statistically, as walking ability improved in both groups. In the correlation analysis among variables obtained using Treadmill, there were significant positive linear relationships between the lateral symmetry and the COP area ($P < .05$), and between the COP velocity and the lateral symmetry ($P < .001$) of the follow-up gait analysis in the right hemiparesis group.

It was confirmed that the gait recovery pattern differs according to the paralyzed side of post-stroke patients and the role of the intact side, such as moving the COP to the intact side, is important for the improvement of gait function in both groups.

This study was registered with the Clinical Research Information Service (CRIS) of the Korea National Institute of Health (NIH), Republic of Korea (KCT0002984) and was approved by the Institutional Review Board (IRB) of the WKUGH (WKIRB [2018-25], November 28, 2018).

Abbreviations: COM = Center of Mass, COP = Center of Pressure, CRIS = Clinical Research Information Service, FAC = Functional Ambulation Category Classification, GDI = Gait Deviation Index, IQR = Interquartile range, IRB = Institutional Review Board, MDC = Minimum Detectable Change, MMT = Manual Muscle Testing, NIH = National Institute of Health, SD = Standard

1. Introduction

Gait rehabilitations have been abundantly performed for post-stroke patients, because gait is the most important factor for the return of post-stroke patients to daily life.[1] However, conventional uniform gait rehabilitations tend to be very tedious and reduce motivation.[2] For these reasons, many studies have recommended personalized rehabilitations for recovery of individual patients.[3] Personalized rehabilitations are being tailored based on the results of analysis of each patient's status.[3] Although there is no report on post-stroke patients, it has been reported that the personalized rehabilitation is effective for walking in patients with multiple sclerosis.[4]

Traditional Korean medicine (TKM) has highly emphasized that treatment of stroke should be tailored based on patients' constitution[5] and focused on paralyzed side of post-stroke patients.[6] Although the evidence for the effectiveness of such personalized treatment is not yet sufficient, the use of paralyzed side information may play a major role in rehabilitation for stroke patients with hemiparesis because stroke patients' symptoms such as aphasia and hemineglect differ depending on the hemisphere which has a lesion.[7,8]

Many studies have measured the movement variables of the stroke patients,[9,10] but all of them were cross-sectional studies comparing normal people with stroke patients, and no follow-up measurements were made. A systematic review has reported that it is important to analyze the movements of the body, including the pelvis, to improve the gait of post-stroke patients.[11] However, to our knowledge, there has been no study showing the differences of gait recovery between left or right hemiparesis patients by measuring pelvic movements and center of pressure (COP) variables.

Considering above the literature and studies,[5–8] we hypothesized that the gait recovery patterns of the stroke patients with left and right hemiparesis would differ. If this is confirmed, reflecting it in the rehabilitation strategy could have a positive effect on the stroke patients' recovery.

The aim of this study was to identify the differences of pelvis movements and COP variables according to the paralyzed side of post-stroke patients using equipments for gait analysis. We report our findings because we obtained significant results.

2. Methods

2.1. Study design and setting

This research work is an observational study based on a retrospective chart review. We divided the subjects into two groups according to the paralyzed side: a right hemiparesis group and a left hemiparesis group.

2.2. Sample size

The hypothesis of this study was that the gait recovery pattern of post-stroke patients with left and right hemiparesis would differ as their walking ability was restored. To calculate the sample size, we searched previous studies to determine the minimum detectable change (MDC) of the symmetrical index (SI). However till now no study was available between divided groups and measured variables except the present one. The SI is obtained by calculating the three-dimensional angles of the pelvis and hips, and a variable called gait deviation index (GDI) is also obtained in a similar way.[12] Thus, we referred to a study[12] that reported the MDC of the GDI. With reference to this study,[12] the sample size was calculated by setting the MDC to 7.5, the standard deviation to 8.15, the power to 80%, and the significant P level to .05. There was a total of 3819 in each group. This study being a retrospective chart review, the dropout rate was not considered.

2.3. Subjects

2.3.1. Inclusion criteria.
The gait analysis data of patients who received TKM and rehabilitation treatment from September 1st, 2017 till June[th], 2018 and who met the following criteria were included and analyzed.

(1) Patients diagnosed with cerebral infarction or hemorrhage on computed tomography or magnetic resonance imaging by a radiologist.
(2) Patients who have not passed 6 months from stroke onset.
(3) Patients with hemiparesis who are able to walk independently; functional ambulation category classification (FAC) 3 to 4
(4) Patients who have two or more clinical data of gait analysis measured at the WKUGH gait analysis center.
(5) Patients who are right-handed, aged between 19 and 85 years.

2.3.2. Exclusion criteria.

(1) Patients with difficulty walking due to other diseases such as musculoskeletal diseases and neurodegenerative diseases.
(2) Patients who did not understand the information given about the study and/or who could not be expected to have the ability to follow the instructions.

2.4. Gait analysis system (Fig. 1)

Gait analysis using G-walk and Treadmill has been performed regularly to evaluate the gait function of post-stroke patients with the protocol of the Wonkwang University Korean Medicine Gwangju Hospital (WKUGH), Korea. We retrospectively reviewed the clinical results of stroke patients who satisfied the inclusion criteria listed above.

2.4.1. Wireless tri-axial accelerometer (G-walk, BTS Bioengineering S.p.A)[13].
Wireless tri-axial accelerometer (G-walk) is a device that measures the subject's center of mass (COM) (Fig. 1a). The data obtained by the accelerometer are transferred to a specific program (G-studio software, version 2.8.16.0) to calculate symmetries of the tilt, obliquity, and rotation of the pelvis (Fig. 2, Table 1).

2.4.2. Force plate treadmill (Zebris Co. Ltd FDM-T)[19].
Force plate treadmill is a device with a force plate embedded in the rail floor (Fig. 1b). When the subject stands on the treadmill, foot
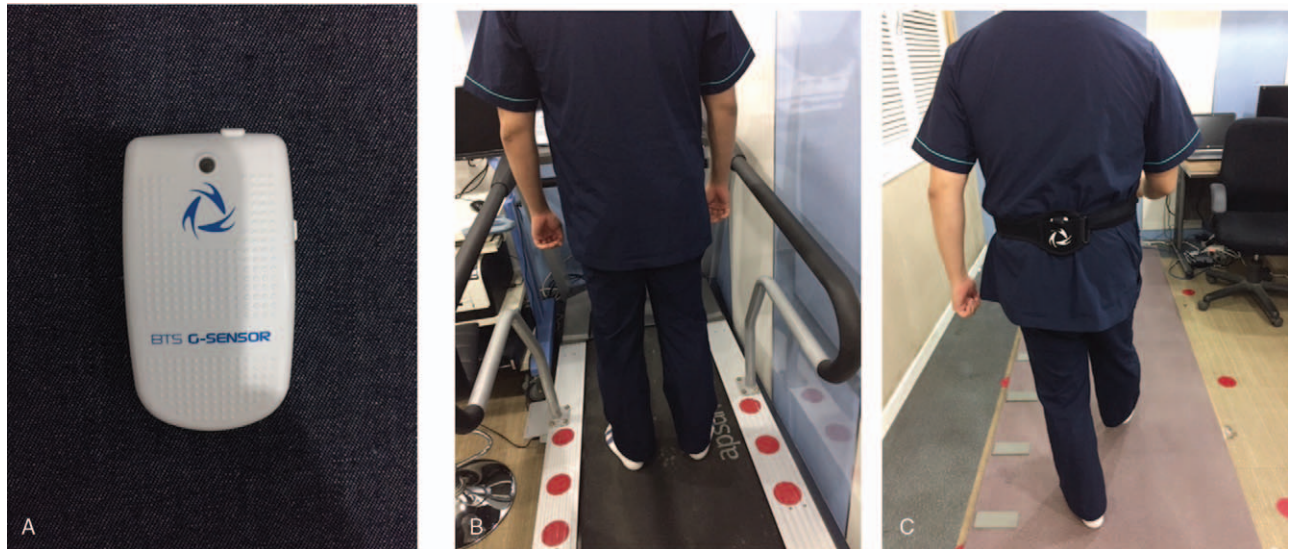
Figure 1. Gait analysis system (A) Wireless tri-axial accelerometer of G-walk and velcro. (B) For gait analysis, the wireless tri-axial accelerometer is attached to the 5th lumbar vertebra of subjects and tightened with velcro by researchers. Then, subjects were instructed to walk barefoot at a preferred speed on a 6-m mat. (C) Next, subjects stand for 10 s and walk at a preferred speed on Treadmill embedded with force plate.
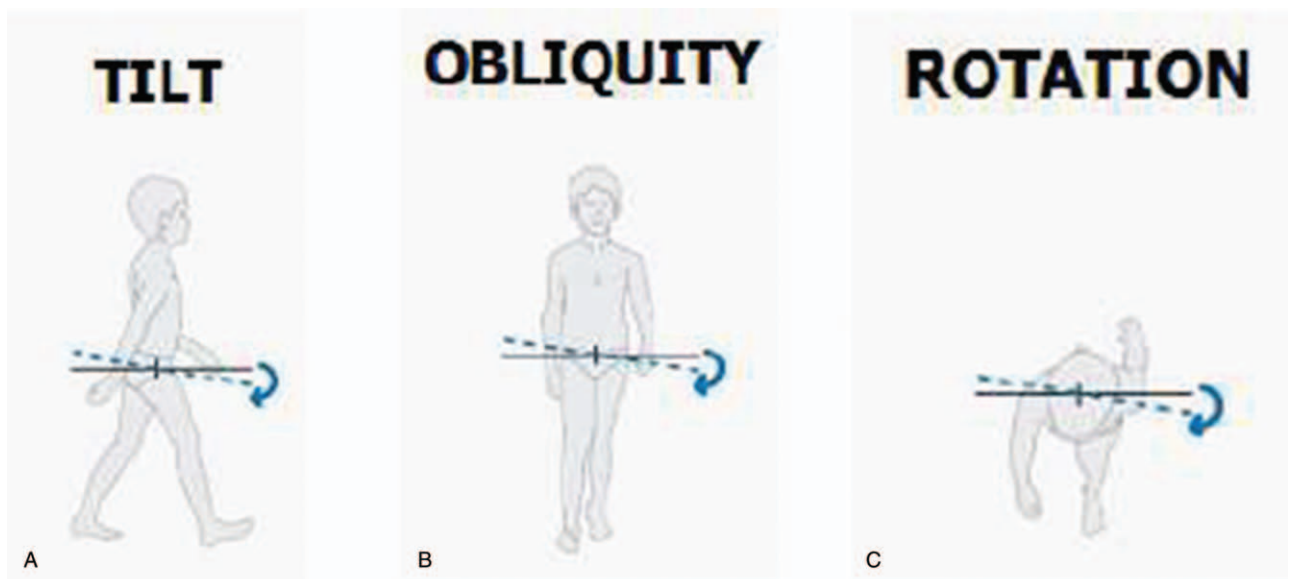
Figure 2. (A) Tilt, (B) Obliquity and (C) Rotation symmetry of pelvis.

pressure and COP are measured. Then, variables such as lateral symmetry, COP velocity and area are calculated by a specific program (Zebris FDM software, version 1.10) (Fig. 3, Table 2).

2.4.3. Gait analysis procedure[13,20,21]. The wireless tri-axial accelerometer was attached to the subject's 5th lumbar vertebra and tightened with a velcro by the guide of the device to measure

Table 1

Variables obtained by G-walk: pelvis tilt symmetry, pelvis obliquity symmetry and pelvis rotation symmetry.

Variable	Explanation
Tilt, obliquity and rotation symmetry of pelvis	Symmetry is an important gait characteristic that is increasingly reported, particularly after stroke.[9] Pelvic movements have significant effect on postural control and gait function.[14] Abnormal pelvic movements such as asymmetrical pelvic tilt, obliquity, and rotation are common in stroke patients. Normalizing pelvic movement in each plane such as frontal plane, sagittal plane and horizontal plane can positively effect the quality and efficiency of hemiplegic gait.[15–18]
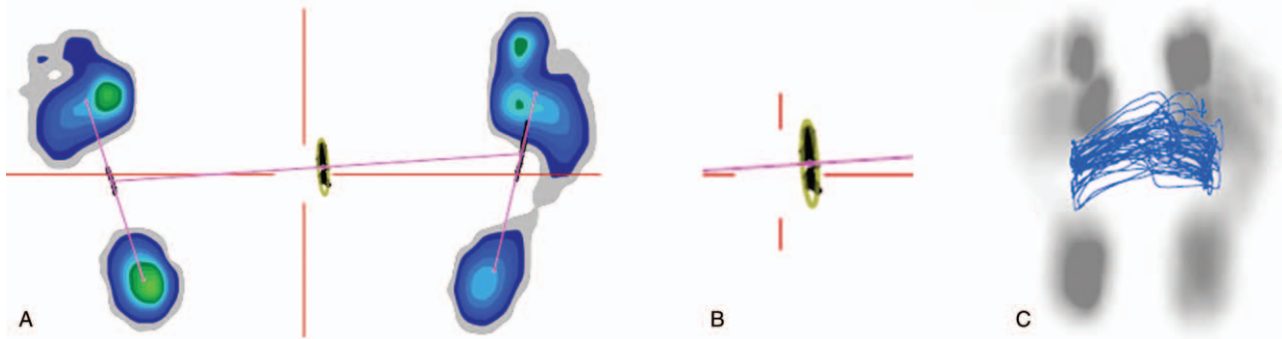
Figure 3. (A) The yellow ellipse and black line represent the area and path of Center of Pressure (COP), respectively. (B) Enlarged view of the change of COP. (C) COP movement during walking.

the symmetry of the pelvis during walking. Then, the subject was asked to walk 6 m at the preferred speed on a 6 m mat (Fig. 1c). The preferred speed has been usually determined during the rehabilitation treatment by the protocol of the clinic.

Next, the subject stands on the force plate treadmill for 10 sec to obtain COP velocity and area. Finally, the subject walks on the treadmill to obtain lateral symmetry.

Two Korean medical specific doctors carried out this procedure and repeated twice per trial to ensure the quality of the measurements. Also, to ensure the validity and reliability of the data, they supervised the subjects to focus on gait analysis. For example, subjects were prevented from speaking and their eyes were directed to the front.

Minimal interval between the initial and follow-up gait analysis was two weeks to evaluate the change of variables (Fig. 4).

The data collected was administered by a researcher with a master's degree in statistics.

2.5. Comparison

With variables including tilt, obliquity, rotation symmetries of pelvis, area, velocity, and lateral symmetry of center of pressure (COP) obtained through gait analysis, intra-group comparisons and inter-group comparisons were performed.

2.6. Ethics and endpoints

This study was registered with the Clinical Research Information Service (CRIS) of the Korea National Institute of Health (NIH), Republic of Korea (KCT0002984) and was approved by the Institutional Review Board (IRB) of the WKUGH (WKIRB [2018-25], November 28, 2018). The study end report was made on December 20th, 2019.

2.7. Statistical analysis

The data obtained from the subjects were analyzed with the IBM SPSS Statistics for Windows Version 20.0 (Armonk, NY: IBM Corp. Released 2010) after coding.

For easy interpretation of the lateral symmetry, we referred the Lee's study[22] in which the direction of the healthy side was coded to positive value and the affected side was coded to negative value.

To check the normality of the data, a frequency analysis was performed for non-continuous variables and a Shapiro –Wilk test (S –W test) was performed for continuous variables. To control confounding factors, independent t-tests or Mann –Whitney U tests were performed for both groups of the gender, age, type of stroke, muscle strength class in the manual muscle testing (MMT), number of days elapsed since the stroke onset, and gait analysis interval. Paired t-tests or Wilcoxon signed-rank tests (Wilcoxon tests) were used to compare the variables between the initial gait analysis and the follow-up gait analysis within the same group. Independent t-tests or Mann –Whitney U tests were used to compare the variables from the initial and follow-up gait analyses between the two groups. A Pearson correlation analysis was performed to see the relationships between the variables obtained from the initial and follow-up gait analyses. All of the analysis results were expressed as a mean±SEM when the normality was satisfied, or as a median and interquartile range (IQR) when the normality was not satisfied. A significance level (P) under.05 was considered to be significant.

3. Results

3.1. General features of left and right hemiparesis groups

The data were from 39 subjects (20 in the left hemiparesis group and 19 in the right hemiparesis group) who performed gait

Table 2		
Variables obtained by treadmill: COP area, COP velocity and lateral symmetry.		
Variable	**Explanation**	
Area, Velocity, and Lateral Symmetry of COP	COP measures are commonly used to assess the standing postural control by measuring the amount of body sway.[20] COP area is the area of ellipse that includes 95% of the path of COP movements. COP velocity is average velocity calculated from the distance that COP moves for 60 s. Small COP area and velocity values mean high stability.[21] Lateral symmetry of COP means COP movements of right and left. The larger the positive value, the more the COP moved to the right and the larger the negative value, the more the COP moved to the left.[22]	

COP = center of pressure.
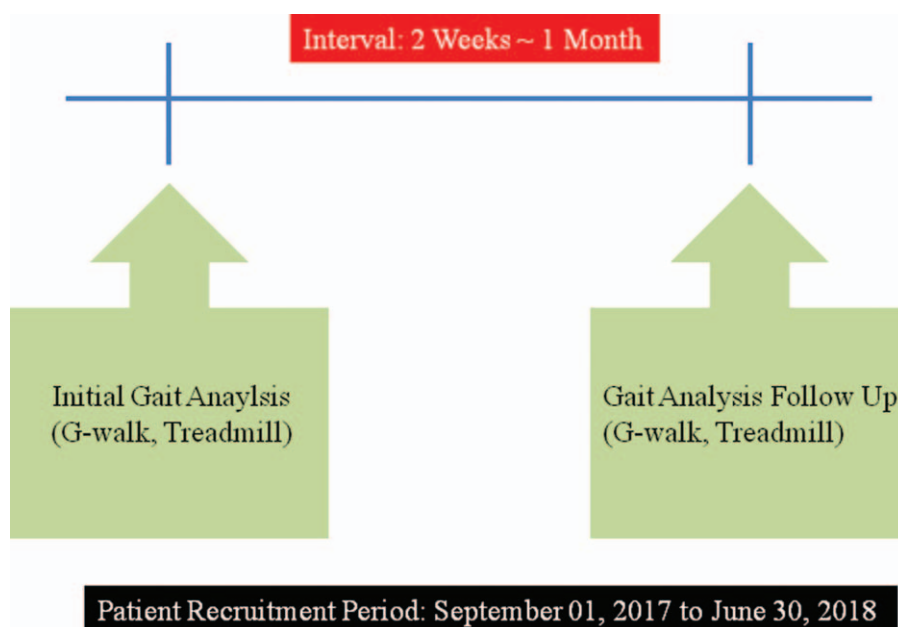
Figure 4. Time schedule of gait analysis: gait analysis is a routine examination performed on stroke patients in Wonkwang University Korean Medicine Hospitals in Gwangju (WKUGH). Among the stroke patients who performed the gait analysis using G-walk and Treadmill more than 2 times during the period from September 01, 2017 to June 30, 2018 in WKUGH, those who satisfies the inclusion criteria becomes the subjects.

analysis from September 1st, 2017 till June 30th, 2018 were analyzed retrospectively. The demographic and clinical characteristics including the gender, age, type of stroke, stroke lesion location, MMT, days since stroke onset, and gait analysis interval did not show a significant difference between the two groups (Table 3). No specific adverse event was reported during the study.

As both groups satisfied the normality in the S – W test, an independent t-test was performed. No significant difference was found in the tilt, obliquity, and rotation symmetries of the two groups.

In the left hemiparesis group, Pearson's correlation analysis showed a significant positive correlation between obliquity and rotation symmetries.

3.2. Gait analysis results using a wireless tri-axial accelerometer

3.2.1. Differences in initial gait analysis variables between the two groups. The mean values (mean ± SEM) of tilt, obliquity, and rotation symmetries in the left hemiparesis group were 81.02 ± 3.07, 53.67 ± 5.59, and 66.27 ± 6.81, respectively. The mean values in the right hemiparesis group for the same

Table 3

Demographic and clinical characteristics of subjects: values are presented as mean (standard deviation) and number (%).

	Left hemiparesis group	Right hemiparesis group	*P* value
Gender (number (%))			
Male	11 (55%)	10 (52.63%)	.88
Female	9 (45%)	9 (47.37%)	
Age (mean (SD)) (min, max, median)	62.70 (9.33)	66.79 (13.63)	.29
	(52, 79, 61.5)	(44, 85, 69)	
Types of stroke (number (%))			
Infarction	15 (75%)	16 (84.21%)	.48
Hemorrhage	5 (25%)	3 (15.79%)	
Stroke lesion location (number (%))			
Carotid circulation[*]	16 (80%)	16 (84.21%)	.45
Posterior circulation[†]	4 (20%)	3 (15.79%)	
MMT (median (IQR))			
Upper limb	4 (0)	4 (3–4)	.17
Lower limb	4 (0)	4 (0)	.96
Days since stroke onset (mean (SD))	46.00 (30.65)	52.42 (43.22)	.59
Gait analysis interval (mean (SD))	19.55 (3.93)	20.42 (4.65)	.53

[*] carotid circulation (anterior circulation): ACA = anterior cerebral artery, MCA = middle cerebral artery.
[†] posterior circulation: BA = basilar artery, IQR = interquartile range, MMT = manual muscle testing, PCA = posterior cerebral artery, SD = standard deviation, VA = vertebral artery.
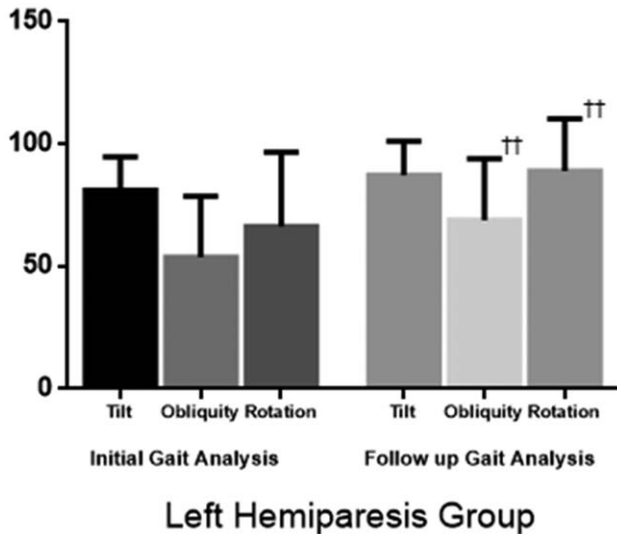
Figure 5. Comparison of variables obtained by G-walk between initial and follow-up gait analysis in left hemiparesis group: tilt symmetry ($P = .05$), obliquity symmetry ($t_{1,19} = 3.22$, $P < .01$) and rotation symmetry ($t_{1,19} = 3.77$, $P < .01$) of initial and follow-up gait analysis $^{††}P < .01$, compared to corresponding values of initial gait analysis.

Figure 6. Comparison of variables obtained by G-walk between initial and follow-up gait analysis in right hemiparesis group: tilt symmetry ($t_{1,18} = 4.69$, $P < .001$), obliquity symmetry ($t_{1,18} = 4.63$, $P < .001$) and rotation symmetry ($t_{1,18} = 2.31$, $P = .03$) of initial and follow-up gait analysis $^{†}P < .05$, $^{†††}P < .001$, compared to corresponding values of initial gait analysis, respectively.

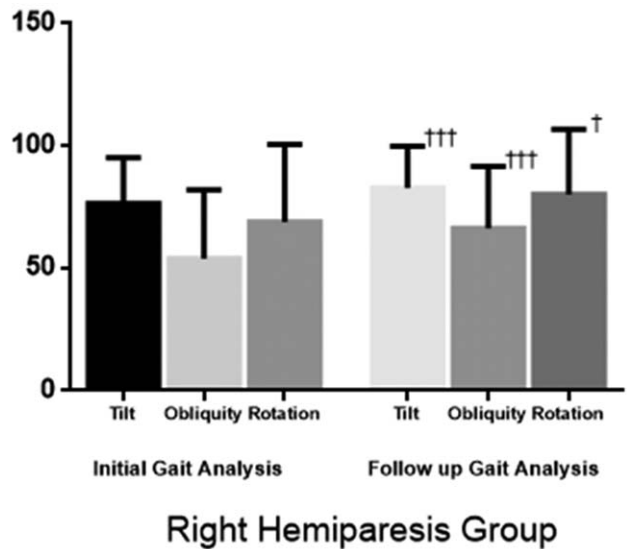variables were 76.27 ± 4.31, 53.76 ± 6.47, and 69.00 ± 7.24, respectively.

3.2.2. Differences in follow-up gait analysis variables between the two groups. The mean values (mean $\pm$ SEM) of tilt, obliquity, and rotation symmetries in the left hemiparesis group were 87.26 ± 3.06, 68.83 ± 5.62, and 88.98 ± 4.78, respectively. The mean values in the right hemiparesis group for the same variables were 82.81 ± 3.89, 66.18 ± 5.82, and 80.16 ± 6.10, respectively.

3.2.3. Differences in variables between initial and follow-up gait analyses. In the left hemiparesis group, there was no significant difference in the tilt symmetry values between the initial gait analysis and follow-up gait analysis. Obliquity and rotation symmetry values of follow-up gait analysis were significantly higher than those of the initial gait analysis (Fig. 5). In the right hemiparesis group, tilt, obliquity, and rotation symmetry values of follow-up gait analysis were significantly higher than those of the initial gait analysis (Fig. 6).

3.2.4. Relevance between variables from initial gait analysis. There seemed to be a positive correlation between tilt and obliquity symmetries, and a negative correlation between tilt and rotation symmetries, however it was not statistically significant (Fig. 7). In the right hemiparesis group, there seemed to be a positive correlation between tilt and obliquity symmetries, between tilt and rotation symmetries, and between obliquity and rotation symmetries. However, none were statistically significant (Fig. 8).

3.2.5. Relevance between variables from follow-up gait analysis. There seemed to be a negative correlation between tilt and obliquity symmetries, and between tilt and rotation symmetries, but it was not statistically significant (Fig. 9). In the right hemiparesis group, there was a positive correlation between tilt and obliquity symmetries, but it was not significant

statistically. There were significant positive correlations between tilt and rotation symmetries, and between obliquity and rotation symmetries (Fig. 10).

3.3. Gait analysis results using Treadmill

3.3.1. Differences in initial gait analysis variables between the two groups. The mean or median values (mean $\pm$ SEM or median (IQR)) of area, velocity, and lateral symmetries of COP in the left hemiparesis group were 401.00 ± 51.31, 16.5 (11.5–40.0), and 0.60 ± 4.54, respectively. The mean or median values in the right hemiparesis group for the same variables were 433.16 ± 64.56, 22.0 (16.0–40.0), and 1.54 ± 4.87, respectively.

3.3.2. Differences in follow-up gait analysis variables between the two groups. The mean or median values (mean $\pm$ SEM or median (IQR)) of area, velocity, and lateral symmetry of COP in the left hemiparesis group were 208.00 ± 32.96, 16.0 (11.0–25.0), and 6.68 ± 2.90, respectively. The mean or median values in the right hemiparesis group for the same variables were 225.263 ± 35.71, 16.0 (11.0–25.0), and 5.15 ± 1.63, respectively.

3.3.3. Differences in variables between initial and follow-up gait analyses. There was no significant difference in the lateral symmetry values between the follow-up and the initial gait analysis (Fig. 11). In the right hemiparesis group, COP area and velocity values of the follow-up gait analysis were significantly smaller than those of the initial gait analysis. And there was no significant difference in the lateral symmetry values between the follow-up and the initial gait analysis (Fig. 12).

3.3.4. Relationships among variables of initial gait analysis. In the left hemiparesis group, there seemed to be a positive correlation between COP area and COP velocity, between COP area and lateral symmetry, and between COP velocity and lateral symmetry, but it was not statistically significant. In the right hemiparesis group, there seemed to be negative correlations
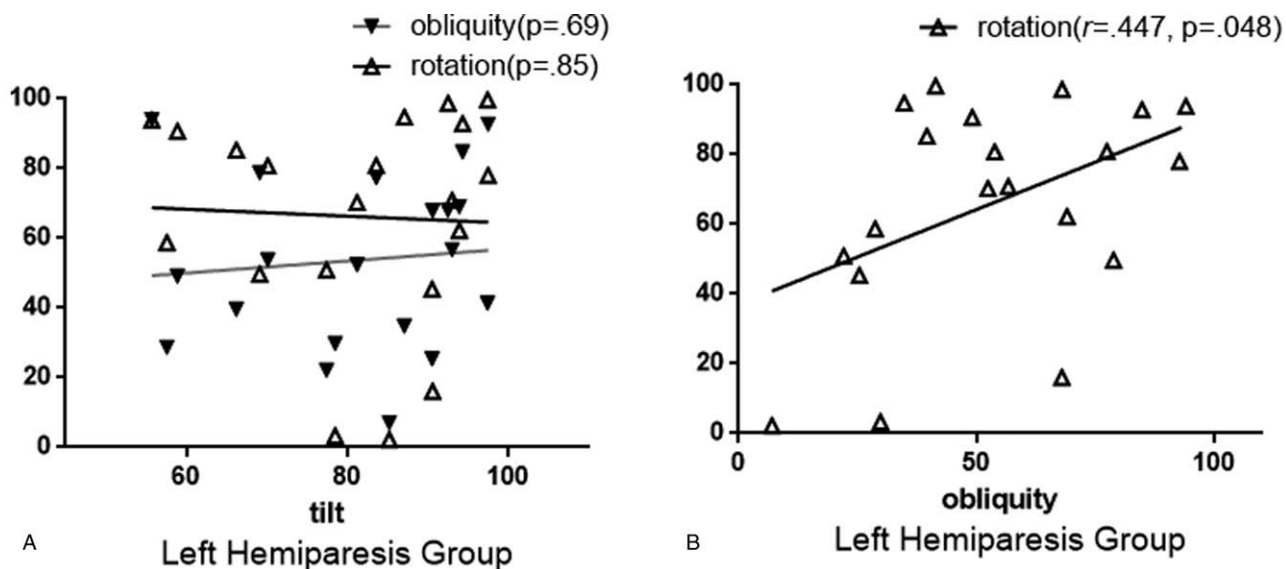
Figure 7. Pearson's correlation analysis results between G-walk variables obtained by initial gait analysis in left hemiparesis group (A) X-axis: tilt symmetry, Y-axis: obliquity symmetry ($P = .69$) and rotation symmetry ($P = .85$) (B) X-axis: obliquity symmetry, Y-axis: rotation symmetry ($r = .447$, $P = .048$).

between COP area and COP velocity, and between COP velocity and lateral symmetry, but it was not statistically significant. In addition, there seemed to be a positive correlation between COP area and lateral symmetry, but it was not significant statistically.

3.3.5. Relationships among variables of follow-up gait analysis. In the left hemiparesis group, there seemed to be a positive correlation between COP area and COP velocity, and between COP area and lateral symmetry, but it was not statistically significant. And there seemed to be a negative correlation between COP velocity and lateral symmetry, but it was not significant statistically. In the right hemiparesis group, there seemed to be a positive correlation between COP area and COP velocity, but it was not significant statistically. And there

was a significant positive correlation between COP area and lateral symmetry, and between COP velocity and lateral symmetry (Fig. 13).

4. Discussion

The main finding of this study was that the COP shifted to the intact side as the walking ability was restored in both groups, but only in the right hemiparesis group, the COP area and velocity increased significantly as the COP shifted. This means that the hemiplegic gait of post-stroke patients could be recovered differently according to the paralyzed side.

As to the symmetry of pelvis, obliquity and rotation symmetries of pelvis in the left hemiparesis group and tilt,
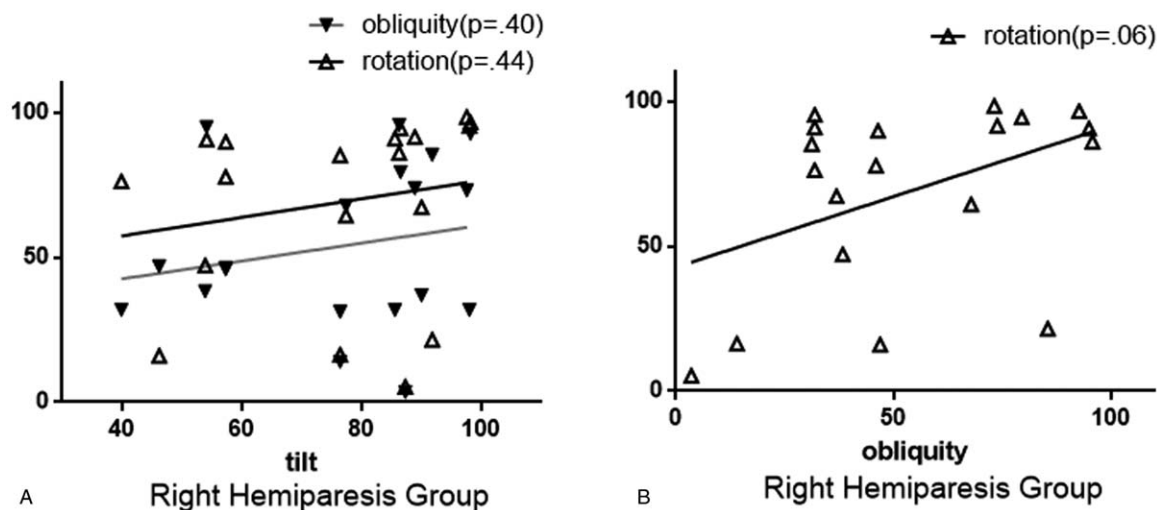
Figure 8. Pearson's correlation analysis results between G-walk variables obtained by initial gait analysis in right hemiparesis group (A) X-axis: tilt symmetry, Y-axis: obliquity symmetry ($P = .40$) and rotation symmetry ($P = .44$) (B) X-axis: obliquity symmetry, Y-axis: rotation symmetry ($P = .06$).
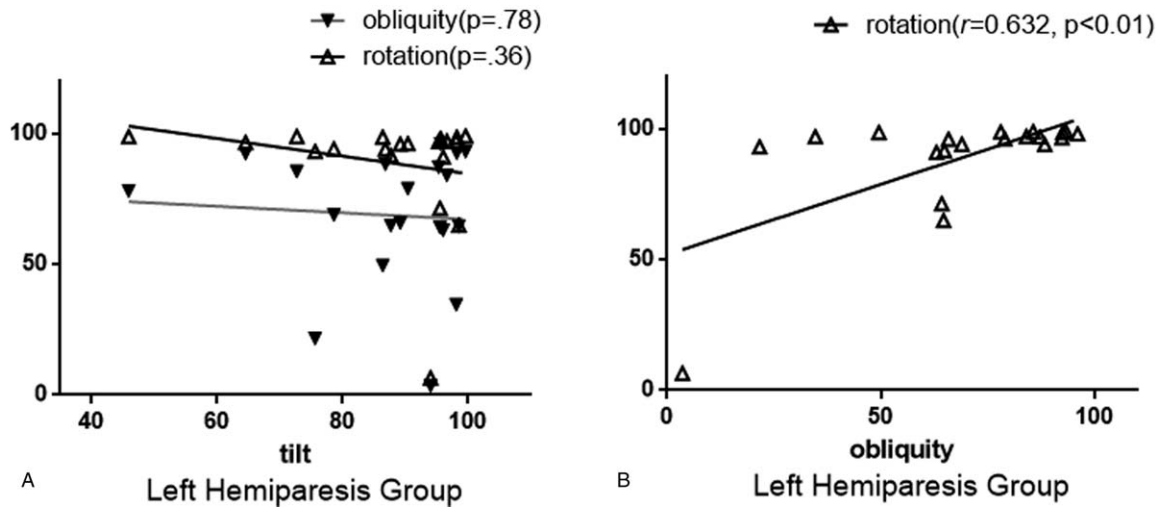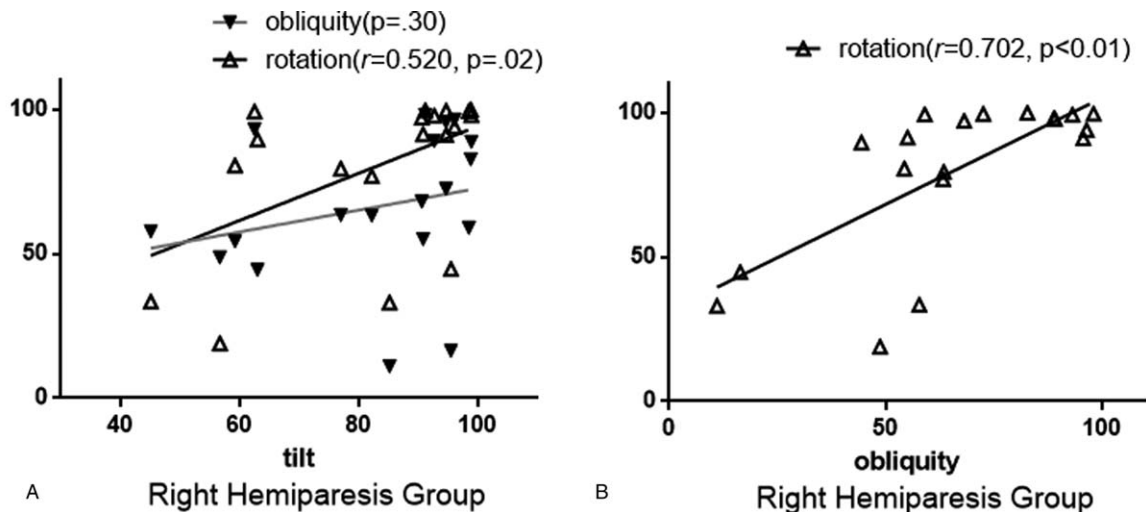
Figure 9. Pearson's correlation analysis results between G-walk variables obtained by follow-up gait analysis in left hemiparesis group (A) X-axis: tilt symmetry, Y-axis: obliquity symmetry ($P=.78$) and rotation symmetry ($P=.36$) (B) X-axis: obliquity symmetry, Y-axis: rotation symmetry ($r=0.632$, $P<.01$).

obliquity, and rotation symmetries of pelvis in the right hemiparesis group were significantly improved in the follow-up gait analysis compared to those in the initial gait analysis, respectively. Although, the tilt symmetry showed a significant improvement only in the right hemiparesis group, the mean value (82.81 ± 3.89) of the tilt symmetry in the follow-up gait analysis of the right hemiparesis group was not significantly different from the mean value (81.02 ± 3.07) in the initial gait analysis of the left hemiparesis group. Therefore, although walking ability was improved in both groups, it is difficult to consider that the recovery of the tilt symmetry of the right hemiparesis group is faster than the left hemiparesis group. Both groups showed the lowest obliquity symmetry values, refers to the angle in the frontal plane of pelvis.[16] This agree with the results of the previous studies,[23,24] which the post-stroke patients had severe instability, especially in the frontal plane, and usually showed hip hiking walk, which is defined as the excessive angle of pelvis in the

frontal plane[15] to clear off the foot of the hemiparesis side from the ground.

COP areas and COP velocities of the left and right hemiparesis patients were significantly smaller and decreased. These results are consistent with those of previous studies that COP area of post-stroke hemiplegic patients was larger than that of the general population[25] and both COP area and COP velocity decreased as walking ability of post-stroke patient improved.[21] The lateral symmetries of COP in both groups was increased in the follow-up gait analysis, which means the COP was moved to the intact side during walking, although it was not statistically significant because of the small sample size. These outcomes are consistent with results of Lee et al's study[22] that COP is moved to an intact side of the both legs at the beginning of independent gait, and stabilizing the COP through the control of the intact leg should be a priority for stable walking of post-stroke patients. In addition, the lateral symmetry of COP was positively correlated

Figure 10. Pearson's correlation analysis results between G-walk variables obtained by follow-up gait analysis in right hemiparesis group (A) X-axis: tilt symmetry, Y-axis: obliquity symmetry ($P=.30$) and rotation symmetry ($r=0.520$, $P=.02$) (B) X-axis: obliquity symmetry, Y-axis: rotation symmetry ($r=0.702$, $P<.01$).
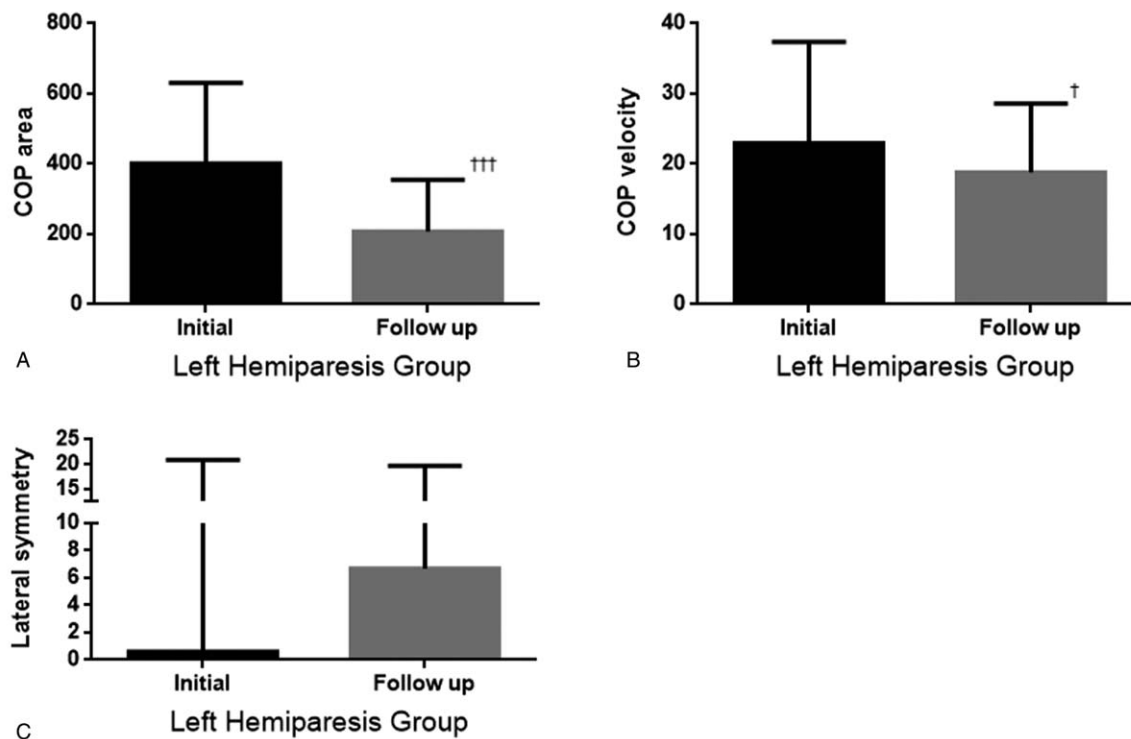
Figure 11. Comparison of variables obtained by Treadmill between initial and follow-up gait analysis in left hemiparesis group (A) COP area ($t_{1,19}$ = 4.67, P < .001) (B) COP velocity (Z = -2.10, P = .03) (C) lateral symmetry (P = .10) of initial and follow-up gait analysis, respectively. [†]P < .05, [†††]P < .001, compared to corresponding values of initial gait analysis, respectively.

with COP velocity and area only in the right hemiparesis group and in the follow-up gait analysis but not in the left hemiparesis group in the initial gait analysis. The COP shift to the intact side, ie left side in the right hemiparesis patients, induces the more instability of body because the high increase of COP area and velocity, led to higher instability. The reason that only the right hemiparesis patients showed the more instability at the beginning of independent gait might be that the strength of the left leg is weaker than that of right leg to support the body in the right-handed persons and all stroke subjects in this study were right-handed persons.

The COP shift is an important consideration for gait rehabilitation, especially at the beginning of the independent gait, because previous studies[23,26,27] reported that the propelling power in gait of post-stroke hemiplegic patients is determined by the force to support the body of the intact lower extremity, and the compensatory strategies such as shifting the COP to the intact side.

Mechanisms to explain our results were explored. Considering the above, it is presumed that the difference in gait recovery patterns between the two groups is due to the difference in the ability to stabilizing COP depending on which intact leg is. In particular, because the instability of the right hemiparesis group tended to increase as the COP moved to the intact side, the rehabilitation strategy to increase the stability of the intact lower extremity seems to be more important in right hemiparesis patients than the left hemiparesis patients.

Interestingly, traditional medicine has addressed that the treatment should be applied to not only a lesion side but also an intact side. The Hwangjenaegyeong and Chimgudaeseong, traditional medicinal texts, have described an acupuncture treatment method, called Geo-ja or Mu-ja, applied to intact side for treating diseases such as hemiparesis, facial palsy, migraine etc.[28,29] Hong et al [30] and Kefeng et al [31] reported that acupuncture treatment on the intact side of post-stroke hemiparesis or shoulder-hand syndrome patients showed a significant therapeutic effect. The acupuncture treatment can also be applied to both sides in some symptoms, such as dysphagia due to stroke, because the muscles of the intact and paralyzed sides are required to be stimulated simultaneously.[32,33]

This study has limitations. First, not all patients had been treated with the exact same rehabilitation treatments. Although there were subtle distinctions of the treatments applying on patients depending on the status of motor grade, cognition etc, the results were not considered to be influenced significantly by these subtle differences of treatment because patients were treated with a conventional protocol of the WKUGH stroke center and we just analyzed the patterns of gait recovery regardless of types of treatment.

Second, since there was no study of similar design to the present study, sample size was calculated by referring to the MDC of the GDI instead of the SI, and the subjects were intentionally selected and assigned into two groups. Furthermore, 39 subjects were insufficient to demonstrate the features of all stroke patients. Nonetheless, a limited number of subjects have yielded important findings that are in line with previous research.

Third, there is a possibility that confounding factors, such as the status of upper limb hemiparesis, handedness and others may influence on the patterns of the gait recovery. However, it would be not influential because we only included right-handed stroke patients, and there was no significant difference between the two
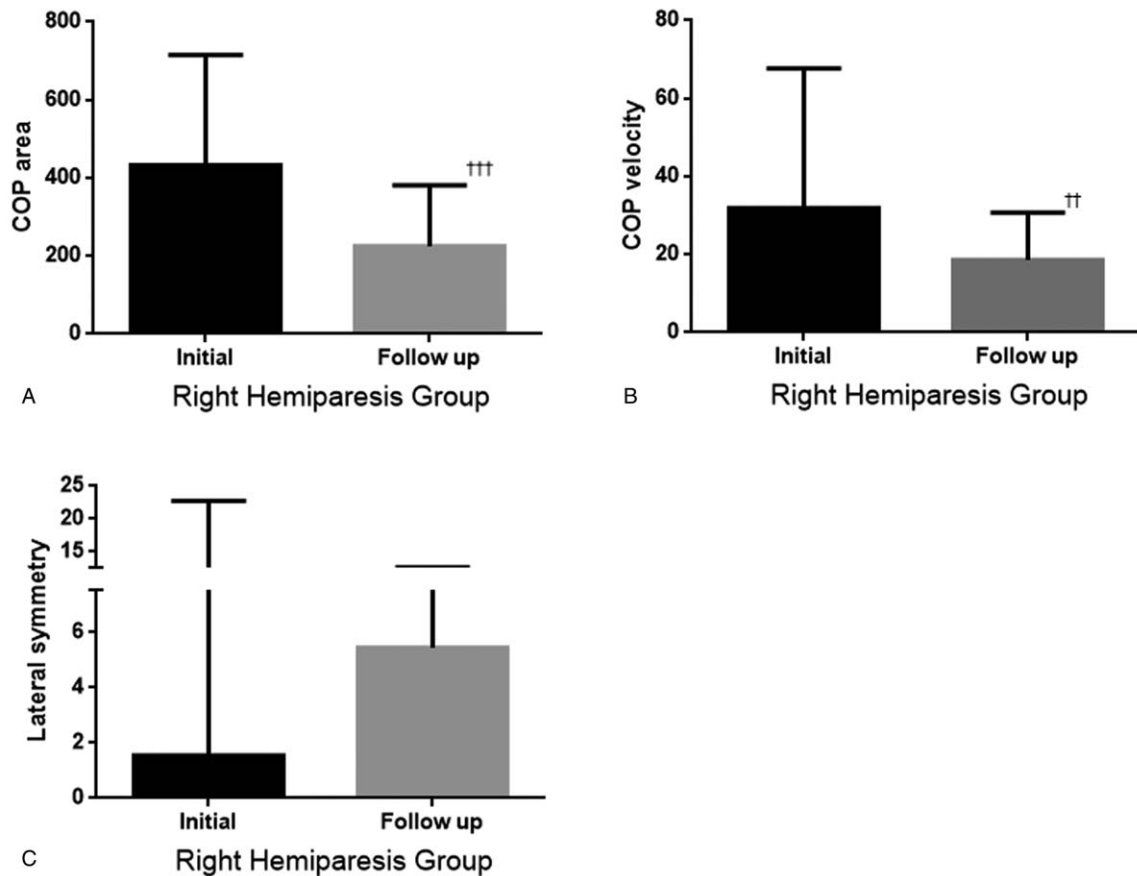
Figure 12. Comparison of variables obtained by Treadmill between initial and follow-up gait analysis in right hemiparesis group (A) COP area ($t_{1,18}$=4.88, P<.001) (B) COP velocity (Z=-2.89, P<.01) (C) lateral symmetry (P=.44) of initial and follow-up gait analysis, respectively. [††]P<.01, [†††]P<.001, compared to corresponding values of initial gait analysis, respectively.

groups in demographic and clinical characteristics including motor grades of upper hemiparesis limb at the initial measures.

Fourth, all the subjects were right-handed, and the left-handed stroke patients may have different walking

recovery patterns from the results of this study. Future studies are required to verify left-handed stroke patients who also shows similar results as right-handed stroke patients do.
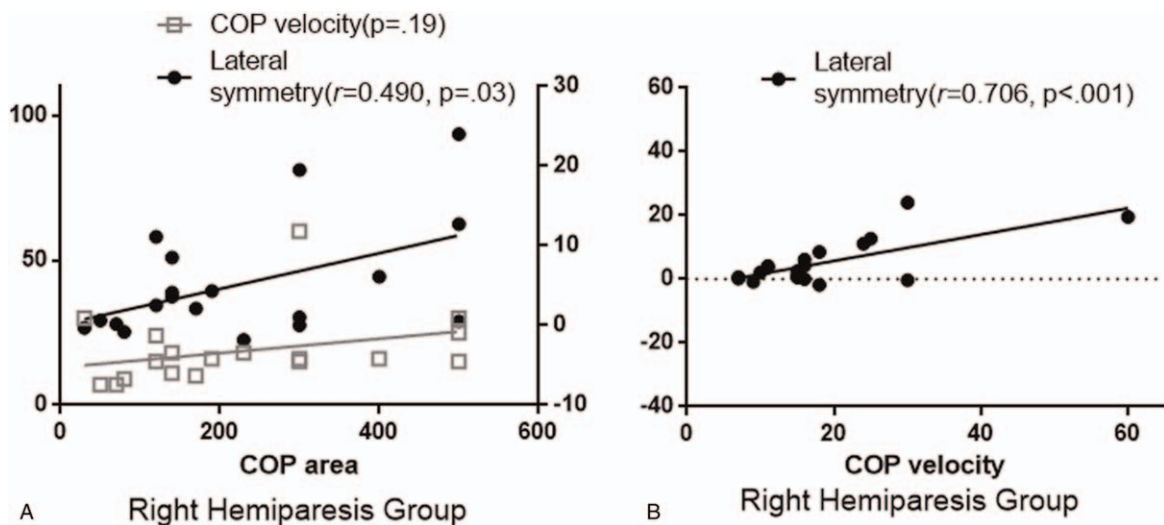
Figure 13. Pearson's correlation analysis results between Treadmill variables obtained by follow-up gait analysis in right hemiparesis group (A) X-axis: COP area, Y-axis: COP velocity (P=.19) and lateral symmetry (r=0.490, P=.03) (B) X-axis: COP velocity, Y-axis: lateral symmetry (r=0.706, P<.001).

5. Conclusion

Despite these limitations, our findings revealed substantial variations in symmetry values and COP changes according to the hemiparesis side over the course of gait rehabilitation, implying that various treatment methods for stroke patients may be used depending on the hemiparesis side. To date, no research has been performed to see how different gait recovery methods impact stroke patients' gait differently depending on the side of the hemiparesis they have. More research is needed to demonstrate the results of prospective clinical trials.

Author contributions

Formal analysis: Geon-hui Kang.
Investigation: Young-ung Lee.
Resources: Kang-keyng Sung.
Software: Hongmin Chu, Kwang-ho Kim, Hyeon-seo Lim.
Supervision: Kang-keyng Sung.
Writing – original draft: Cheol-hyun Kim.
Writing – review & editing: SANGKWAN LEE.

References

[1] Hamza AM, Al-Sadat N, Loh SY, et al. Predictors of poststroke health-related quality of life in Nigerian stroke survivors: a 1-year follow-up study. BioMed Res Int 2014;2014:350281.

[2] Delden RV, Janssen J, Stal ST<ET AL>. Personalization of gait rehabilitation games on a pressure sensitive interactive LED floor. Proceed Personal Persuas Technol Workshop, Persuasive Technol 2016.

[3] Ferrante S, Chia Bejarano N, Ambrosini E<ET AL>. A personalized multi-channel FES controller based on muscle synergies to support gait rehabilitation after stroke. Fron Neurosci 2016;10:425doi: 10.3389/fnins.2016.00425.

[4] Kalron A, Nitzani D, Magalashvili D, et al. A personalized, intense physical rehabilitation program improves walking in people with multiple sclerosis presenting with different levels of disability: a retrospective cohort. BMC Neurol 2015;15: doi: 10.1186/s12883-015-0281-9.

[5] Kim , Jong Yeol, Pham , et al. Sasang constitutional medicine as a holistic tailored medicine. Evid Based Complement Alternat Med 2009;6(S1):11–9.

[6] Heo J, Jinjupyo F. Donguibogam Seoul: bubinbooks. XXXX 2009; 445:823.

[7] Knecht S, Dräger B, Deppe M, et al. Handedness and hemispheric language dominance in healthy humans. Brain 2000;123:2512–8.

[8] Weintraub S, Mesulam M-M. Right cerebral dominance in spatial attention: further evidence based on ipsilateral neglect. Arch Neurol 1987;44:621–5.

[9] Patterson KK, Gage WH, Brooks D, et al. Evaluation of gait symmetry after stroke: a comparison of current methods and recommendations for standardization. Gait Posture 2010;31:241–6.

[10] McDonough AL, Batavia M, Chen FC, et al. The validity and reliability of the GAITRite system's measurements: a preliminary evaluation. ArcPhys Med Rehabil 2001;82:419–25.

[11] Van Criekinge T, Saeys W, Hallemans A, et al. Trunk biomechanics during hemiplegic gait after stroke: a systematic review. Gait Posture 2017;54:133–43.

[12] Correa KP, Devetak GF, Martello SK, et al. Reliability and minimum detectable change of the gait deviation Index (GDI) in post-stroke patients. Gait Posture 2017;53:29–34.

[13] Wu Y-T, Choe Y-W, Peng C, et al. The immediate effects of posterior pelvic tilt with taping on pelvic inclination, gait function and balance in chronic stroke patients. Korean Soc Phys Med 2017;12:11–21.

[14] Kim M-K, Kim S-G, Shin Y-J, et al. The relationship between anterior pelvic tilt and gait, balance in patient with chronic stroke. J Phys Ther Sci 2017;30:27–30.

[15] Cruz TH, Lewek MD, Dhaher YY. Biomechanical impairments and gait adaptations post-stroke: multi-factorial associations. J Biomech 2009; 42:1673–7.

[16] Kischner M, Miller J. Can hemiplegic gait be improved by emphasizing pelvic position? School Phy Therapy 2004.

[17] Olney SJ, Richards C. Hemiparetic gait following stroke. part I: characteristics. Gait Posture 1996;4:136–48.

[18] Lee M, Song C, Lee K, et al. Agreement between the spatio-temporal gait parameters from treadmill-based photoelectric cell and the instrumented treadmill system in healthy young adults and stroke patients. Int Med Sci J Exp Clin Res 2014;20:1210.

[19] Marigold DS, Eng JJ. The relationship of asymmetric weight-bearing with postural sway and visual reliance in stroke. Gait Posture 2006; 23:249–55.

[20] Hong HJ, Kim CH, Lee IS, et al. Change in center of pressure according to gait improvement of post-stroke hemiplegic patients: pilot study. J Intern Korean Med 2015;36:478–85.

[21] Lee IS, Park KE, Hong HJ, et al. The change of lateral shift of center of pressure according to the gait improvement in post-stroke hemiplegic patients. J Intern Korean Med 2014;35:448–54.

[22] de Haart M, Geurts AC, Huidekoper SC, et al. Recovery of standing balance in postacute stroke patients: a rehabilitation cohort study. Arch Phys Med Rehabil 2004;85:886–95.

[23] Kerrigan DC, Frates EP, Rogan S, et al. Hip hiking and circumduction: quantitative definitions. Am J Phys Med Rehabil 2000;79:247–52.

[24] Das S, Tibarewala D. Stabilometric postural steadiness analysis of poststroke hemiplegic patients. Int J Eng Sci Tech 2011;3:4626–37.

[25] Dettmann MA, Linder MT, Sepic SB. Relationships among walking performance, postural stability, and functional assessments of the hemiplegic patient. Am J Phys Med Rehabil J 1987;66:77–90.

[26] Mahon CE, Farris DJ, Sawicki GS, et al. Individual limb mechanical analysis of gait following stroke. J Biomech 2015;48:984–9.

[27] Kim JK, Kim KH, Kim GS. Philological study on chapter of official acupuncture, Youngchu. J Acupunct Res 1998;15:163–79.

[28] Ahn K-B, Wang W-H, Lim J-K, et al. Clinical study of acupuncture effect by measuring amperage from chong points. Acupunct 2001;18.

[29] Hong J, Sheng P, Yuan Y, et al. Observation on therapeutic effect of opposing needling for treatment of poststroke shoulder-hand syndrome. Chin Acupunct Moxibust 2009;29:205–8.

[30] Kefeng N, Yanning L, Yanwu W. Clinical observation of recuperative effect of opposing needling accompanying continual static stretch in treating high muscular tension of apoplectic hemiplegia. J Zhejiang Univ Trad Chin Med 2009;4:70.

[31] Hamdy S, Aziz Q, Thompson D, et al. Physiology and pathophysiology of the swallowing area of human motor cortex. Neural Plast 2001;8:91–7.

[32] Hamdy S. The organisation and re-organisation of human swallowing motor cortex. Suppl Clin Neurophysiol 2003;204–10.

[33] Kim SI, Kim WS, Cho KJ. The type of handedness and correlation analysis of handedness assessment items on university students in Korea. Anat Biol Anthropol 2008;21:245–53.