Hong Kong Physiotherapy Journal (2017) **37**, 19–24

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.hkpj-online.com

RESEARCH PAPER

Relationship between dynamic balance and spatiotemporal gait symmetry in hemiplegic patients with chronic stroke

Chang-Man An, MSc, PT [a,b,*], Young-Lan Son, MSc, PT [a], Young-Hyun Park, MSc, PT [a,b], Sung-Jun Moon, MSc, PT [a,c]

[a] *Department of Physical Therapy, Chonbuk National University Hospital, Chonbuk, Republic of Korea*
[b] *Department of Physical Therapy, Graduate School, Hanseo University, Republic of Korea*
[c] *Department of Rehabilitation Science, Graduate School, Daegu University, Republic of Korea*

KEYWORDS
dynamic balance;
heel-to-heel base of support;
spatiotemporal gait symmetry;
stroke

Abstract *Background:* Poor dynamic balance, which is common after stroke, may affect gait function. In particular, spatiotemporal asymmetrical gait patterns may occur in hemiplegic patients after stroke.
Objective: This study aimed to assess the relationship between dynamic balance and spatiotemporal gait symmetry in patients with chronic hemiplegic stroke.
Methods: To calculate symmetry ratios for step length (spatial parameter) and swing time (temporal parameter), 41 patients with chronic stroke walked at a comfortable speed. The dynamic balance measures included limit of stability (LOS) during standing and heel-to-heel base of support (H-H BOS) during gait. Analysis of correlations between various measures was performed.
Results: The overall LOS score correlated with temporal gait symmetry ($r = 0.66$). The forward, backward, paretic, and non-paretic direction LOS scores were related to temporal gait symmetry ($r = 0.38$–0.62). The H-H BOS was correlated with temporal ($r = -0.63$) and spatial ($r = -0.36$) gait symmetries. Other dynamic balance variables were not significantly correlated with spatial gait symmetry.
Conclusion: Thus, control of dynamic balance abilities is related to the magnitude of temporal gait symmetry. This observation suggests that rehabilitation strategies that improve dynamic balance may enhance temporal gait symmetry in post-stroke patients.

* Corresponding author. Department of Physical Therapy, Chonbuk National University Hospital, Geonji-ro 21, Deokjin-gu, Jeonju-si, Chonbuk-do, 54907, Republic of Korea.
E-mail address: dks3597@hanmail.net (C.-M. An).

http://dx.doi.org/10.1016/j.hkpj.2017.01.002
1013-7025/

Introduction

The ultimate goal of gait therapy for stroke survivors is safe and efficient locomotion [1]. Improving gait function in stroke patients ensures independent daily living and social participation [2,3]. However, even after physiotherapy, many stroke survivors still experience muscle weakness, abnormal movement synergies, spasticity, and limited range of motion [4]. In addition, they may have increased asymmetry in body weight distribution between the non-paretic and paretic limb during quiet standing [5]. This tendency to maintain the centre of gravity (COG) shifted toward the non-paretic limb is also observed during gait [6]. As a result, spatiotemporal asymmetrical gait patterns may occur in hemiplegic patients after stroke [7,8]. Spatiotemporal gait asymmetry is associated with (1) impaired balance control; (2) gait inefficiencies and slower gait speed; and (3) musculoskeletal injury of the non-paretic lower limb [7—9].

Previous studies attempted to identify the determinants of gait asymmetry [4,7,9]. Spasticity, impaired proprioception, and muscles weakness were found to be correlated with spatiotemporal gait asymmetry [4,9,10]. Recent studies reported that, in addition to kinematic factors of the paretic lower limb, quiet standing balance function is associated with asymmetric gait patterns of stroke patients [11—13]. Hendrickson et al [12] reported that reduced weight bearing of the paretic limb during quiet standing increases spatiotemporal asymmetry gait patterns. Lewek et al [13] observed a significant relationship between standing balance function and spatiotemporal gait asymmetry. Reduced muscle strength on the paretic side of the lower limb resulted in a weight distribution towards the non-paretic side during quiet standing and increased medial-lateral (M-L) deviation of COG during gait in patients with stroke compared with that in an age-matched healthy group [11]. Although standing balance and gait are different levels of functional activities, they have a number of interdependencies and associations at many different levels of the central nervous system [14].

However, the scope of previous studies was limited to the association between static balance ability [11,12], i.e., the degree of weight distribution towards the unaffected limb, or clinical balance scale rather than data through computerised apparatus and asymmetric gait patterns during quiet standing or mobility [13], which, in contrast to dynamic balance data through computerised apparatus, does not involve body weight shifting in a specific direction (i.e., paretic side or non-paretic side) during standing or walking. The results did not fully explain the association between gait asymmetry and dynamic balance ability during standing or walking in hemiplegic stroke patients. Therefore, this study assessed the relationship between spatiotemporal gait symmetry during gait at a comfortable speed and measured the dynamic balance function during standing or walking in hemiplegic patients with chronic stroke. We hypothesised that spatial and temporal gait asymmetries are associated with impairments in dynamic balance control during standing and gait in these patients.

Materials and methods

Patients

A power analysis was performed using the G-power software version 3.1.2 (Franz Faul, University of Kiel, Kiel, Germany) to achieve a significant level of 0.05, power of 0.80, and effect size of 0.9 at the two-tails. The results of the power analysis showed that this study would require 38 patients. Our study included 41 patients with stroke (25 males; age, 49.39 ± 10.30 years) who were recruited while undergoing physiotherapy at the University's neurological rehabilitation outpatient department. The inclusion criteria were: (1) hemiplegic stroke that occurred more than 6 months before testing; (2) ability to walk independently without an assistive device for more than 10 m on a level surface; and (3) ability to follow verbal instructions. Patients were excluded for: (1) orthopaedic conditions (e.g., fracture, trauma, inflammation) or additional neurologic conditions (e.g., Parkinson's disease) that would influence gait; (2) cerebellar lesions; and (3) bilateral stroke lesions. All patients read and signed an informed consent document approved by the institution's Research Ethics Board and composed in accordance with the Declaration of Helsinki.

Outcome measures and data analysis

Measured dynamic balance function during standing

Dynamic balance function during standing was measured using a Biodex balance system (Biodex Medical System, NY, USA). Dynamic balance ability was assessed using the limit of stability (LOS) test. This test evaluates the ability of patients to move and control their COG within their base of support without losing balance or stepping. The LOS test measures the time and accuracy of transferring the estimated COG while moving a cursor to intercept each of eight successive targets on a display screen [15]. The eight targets were randomly highlighted, and the patient reached the target by leaning and returning to the centre position before the next target was selected and displayed on the screen. The test was complete when all the eight targets were reached. Patients were instructed to move the COG cursor as quickly and accurately as possible towards the highlighted target as soon as a visual signal, in the form of a circle, moved from the centre starting target without losing balance and stepping. A high LOS score signifies superior dynamic balance ability. Three trials were recorded for each patient, and the average was used for subsequent analysis. Averaged direction control scores for forward, backward, paretic, and non-paretic directions were used for statistical analysis. The formulas for calculating direction LOS (DLOS) scores and the overall LOS (OLOS) score are as follows [15]:

$$\text{DLOS score }(\%) = \frac{\text{straight line distance to target}}{\text{actual distance traveled}} \times 100$$

$$\text{OLOS score }(\%) = \sum_{i=1}^{i=4} (\text{DLOS score}) \div 4 \,(\text{average of four targets})$$

Measured spatiotemporal gait symmetry and dynamic balance function during gait

Spatiotemporal gait parameters were recorded and analysed using the GAITRite system (GAITRite, CIR System, Clifton, NJ, USA). Before data collection, patients performed one walking trial to familiarise themselves with the procedure. They subsequently completed three trials of walking at their preferred speed across a level of 10 m walkway with a pressure-sensitive mat in the middle [7]. Patients were requested to perform these trials without their gait-assistive device. The three trials were recorded for each patient, and the average was used for subsequent analysis. The following variables were obtained: gait velocity, paretic and non-paretic step length, and swing time. Spatial (step length) and temporal (swing time) gait symmetry indices were calculated as below [12]:

$$\text{Symmetry index} = \frac{\text{Non} - \text{paretic limb value}}{(\text{Paretic limb value} + \text{Non} - \text{paretic limb value})}$$

The gait symmetry index ranges from 0 to 1. A gait symmetry index of 0.5 indicates equal values of the paretic and non-paretic limbs (i.e., perfect symmetry). A symmetry index of < 0.5 indicates that the paretic limb has a greater value than the non-paretic limb, whereas an index value > 0.5 indicates that the non-paretic limb has a greater value than the paretic limb for that variable [12].

Among the variables measured using GAITRite, heel-to-heel base of support (H-H BOS) was used to assess dynamic balance ability during gait. H-H BOS was defined as the perpendicular distance from the heel point of one footfall to the line of progression of the opposite foot. A lager H-H BOS indicated reduced dynamic balance ability during gait.

Statistical analysis

Data were statistically analysed using PASW statistics for Windows version 18.0 (SPSS Inc., Chicago, IL, USA). A significance level of $p < 0.05$ was used for all statistical analyses. Descriptive analyses were conducted to understand the general characteristics. Relationships between spatiotemporal gait symmetry index and dynamic balance variables were characterised using the Pearson correlation coefficient (r).

Results

In total, 41 patients participated in this study. Table 1 summarises their general characteristics. The average value of the OLOS score was 47.54 ± 20.09% (range: 19.25–89.25%). The average values of the forward and backward direction LOS scores were 43.81 ± 23.35% (range: 12.00–98.00%) and 42.13 ± 24.27% (range: 11.00–91.00%), respectively. The average values of the paretic and non-paretic direction LOS scores were 44.48 ± 21.65% (range: 14.00–87.00%) and 59.74 ± 18.39% (range: 31.00–84.00%), respectively. The H-H BOS average value was 15.43 ± 5.12 cm (range: 4.45–28.07 cm). The average values of the paretic and non-paretic step length were 0.44 ± 0.09 cm (range: 0.24–0.67 cm) and 0.37 ± 0.12 cm (range: 0.14–0.68 cm), respectively. The average values of the paretic and non-paretic swing time were 0.75 ± 0.13 s (range: 0.53–1.01 s) and 0.59 ± 0.09 s (range: 0.48–0.81 s), respectively. Finally, the average value of the spatial gait symmetry index was 0.44 ± 0.06 (range: 0.30–0.50), whereas that of the temporal gait symmetry index was 0.43 ± 0.05 (range: 0.31–0.49) (Table 2).

Correlation analysis revealed a positive relationship between temporal gait symmetry index and OLOS score ($r = 0.66$) (Table 3). There was a positive relationship between temporal gait symmetry index and forward direction LOS score ($r = 0.61$) and backward direction LOS score ($r = 0.39$) (Table 3). There was also a positive relationship between temporal gait symmetry index and paretic direction LOS score ($r = 0.62$) and non-paretic direction LOS score ($r = 0.58$) (Table 3). In addition, there was a negative relationship between H-H BOS and temporal gait symmetry index ($r = -0.63$) and spatial gait symmetry index ($r = -0.36$) (Table 3). Finally, there was no significant relationship between spatial gait symmetry index and the remaining dynamic balance variables, both during standing and gait (Table 3).

Discussion

Spatial gait asymmetry and temporal gait asymmetry are common impairments after stroke [4,7,10,12,13]. Asymmetric gait patterns induce gait instability, resulting in high risk of falls and gait inefficiency [7,8]. The main purpose of this study was to verify the correlation between gait symmetry and dynamic balance ability while standing or walking in patients with chronic stroke. The main finding of our study is that control of dynamic balance during both

Table 1 Clinical features of patients.

Characteristics	Values	Range
Age (y)	49.39 ± 10.30	29–71
Sex (M/F)	25/16	
Hemiplegic side (R/L)	22/19	
Type of stroke (ischemia/haemorrhage)	20/21	
Disease duration (mo)	55.61 ± 35.78	16–156
Height (cm)	168.19 ± 6.85	153–181
Weight (kg)	65.0 ± 6.36	49–84
MBI	83.97 ± 5.87	72–93
Gait velocity(m/s)	0.63 ± 0.23	0.29–1.27

Values are expressed as mean ± standard deviation or frequency.
F = female; L = left; M = male; MBI = modified Barthel index; R = right.

Table 2 Dynamic balance and spatiotemporal gait parameter.

Measurements			Values	Range
Dynamic balance parameters	LOS (%)	Overall	47.54 ± 20.09	19.25–89.25
		Forward	43.81 ± 23.35	12.00–98.00
		Backward	42.13 ± 24.27	11.00–91.00
		Paretic	44.48 ± 21.65	14.00–87.00
		Non-paretic	59.74 ± 18.39	31.00–84.00
	H-H BOS (cm)		15.43 ± 5.12	4.45–28.07
Spatiotemporal gait parameters	Step length (cm)	Paretic	0.44 ± 0.09	0.24–0.67
		Non -paretic	0.37 ± 0.12	0.14–0.68
	Swing time (s)	Paretic	0.75 ± 0.13	0.53–1.01
		Non-paretic	0.59 ± 0.09	0.48–0.81
	Spatial gait symmetry index (%)		0.44 ± 0.06	0.30–0.50
	Temporal gait symmetry index (%)		0.43 ± 0.05	0.31–0.49

H-H BOS = heel-to-heel base of support; LOS = limit of stability.

Table 3 Correlations between dynamic balance measures and gait symmetry ratios.

Measurements	Spatial gait symmetry index	Temporal gait symmetry index
Overall LOS	0.315	0.660**
Forward direction LOS	0.298	0.608**
Backward direction LOS	0.205	0.383*
Paretic direction LOS	0.335	0.617**
Non-paretic direction LOS	0.395	0.575**
H-H BOS	−0.359*	−0.632**

Significant at *$p < 0.05$; **$p < 0.01$.
H-H BOS = heel-to-heel base of support; LOS = limit of stability.

standing and gait is significantly related to the magnitude of temporal gait symmetry. That is, higher LOS scores (i.e., efficient weight shifting in multiple directions) during standing and a narrower distribution of H-H BOS values were associated with better temporal gait symmetry in both the lower limbs.

Lewek et al [13] reported a significant relationship between spatiotemporal gait asymmetry and standing balance function. In particular, they found a significant association between weight distribution while standing and gait symmetry in patients with chronic stroke, and a higher correlation was observed between gait symmetry and standing balance function in dynamic tasks than in static tasks using the Berg balance scale [13]. Hendrickson et al [12] reported increased weight bearing on the non-paretic limb during quiet standing; this tendency reduced balance control of the paretic limb and was related to increased asymmetry of the spatiotemporal gait features [16].

We observed increased temporal gait symmetry among patients with greater ability to adjust their COG in both anterior-posterior (A-P) and M-L directions without losing balance within a fixed BOS in a standing position. Hemiplegic patients typically exhibit difficulties in shifting body weight towards the paretic lower limb, and limited shifts of weight towards the paretic side result in further instability in the stance phase and ultimately to a shortened swing phase of the non-paretic lower limb. However, the ability to shift weight in the A-P and M-L directions, including the paretic direction, allows a more stable stance phase during gait, thereby resulting in a prolonged swing phase of the non-paretic lower limb and improved temporal symmetry. These findings are further supported by the study of Patterson et al [17], which reported improved symmetry in swing time with increased weight bearing ability of the paretic lower limb.

In this study, a narrower distribution of H-H BOS values accompanied improved dynamic balance during gait and was also associated with increased gait speed. This finding is consistent with previously published results [18,19]. Furthermore, a significant negative relationship was observed between H-H BOS values and spatiotemporal gait symmetry, which emphasised the higher correlation with temporal gait symmetry. Patients with better dynamic balance function during the gait phase were able to walk within a narrow BOS, indicating their ability to shift their COG in all A-P and M-L directions without losing balance. Lewek et al [13] reported that patients with greater spatiotemporal gait asymmetry exhibited a greater step width, and a greater step width was associated with reduced balancing ability. In conclusion, these observations indicate that there is an association between balancing and walking abilities.

Surprisingly, there was little or no correlation between dynamic balance ability and spatial gait symmetry. Specifically, there was no correlation between dynamic balance ability during standing and spatial gait symmetry, while a weak correlation was observed in the walking phase. These results are in disagreement with previous results [11–13]. Factors such as spasticity of the ankle plantarflexor or swing trajectory contribution of the ankle dorsiflexor and plantarflexor of the lower limb had a greater association with spatial gait symmetry patterns and played a more significant role than dynamic balance ability, such as weight shifting, in determining spatial gait symmetry patterns [4,10,20]. Spasticity in the muscles around the paretic ankle during gait results in stance phase instability and limited weight support, thereby reducing the step length of the non-paretic limb compared to that of the paretic limb [4,10]. Reduced strength of the muscles surrounding the ankle joint may be directly related to the shortened step length of the paretic limb. The plantarflexor elongates steps by forming the ground reaction force in the pre-swing phase [20,21], while dorsiflexors prevent dragging of the feet against the ground surface or premature contacting, thus directly increasing the step length [21]. Therefore, spatial gait symmetry shows a stronger association with factors that directly impact the step length of the lower limb, such as ankle spasticity and muscle strength, rather than with dynamic balance abilities, such as weight shifting.

This study has some limitations. First, individual lesion locations and lower limb proprioception were not considered when selecting the patients. Spatiotemporal gait asymmetry increases in patients with stroke with lesions located in the putamen [22] and with reduced proprioception of the lower limb [23]. Although these variables can affect the dependent variable (gait asymmetry), they were not considered when enrolling patients. Second, the ratio between sexes of the patients was not balanced. Although previous studies do not indicate that sex influences gait asymmetry, its potential effects are unknown. Third, the sample size was small, making it difficult to generalise the statistical findings. These limitations should be considered or addressed in future studies.

Conclusion

In summary, temporal gait symmetry was greater in both standing and gait phases in patients with better dynamic balance ability. In other words, temporal gait asymmetry in patients after hemiplegic stroke increased with increasing difficulty in weight shifting towards the paretic lower limb during standing or gait. However, there was no association between spatial gait symmetry and dynamic balance ability, or such an association was weak. Interventions to improve gait symmetry should consider specific methods, directed at enhancing either spatial or temporal gait symmetry, depending on patient's individual characteristics. In cases where temporal gait symmetry needs to be improved, interventions aimed at improving dynamic balance ability (i.e., weight shifting training) are recommended. In order to improve spatial gait symmetry, factors enhancing functional movement of the lower limb, including kinematic factors such as muscle strength, spasticity, and joint mobility, should be considered.

Conflicts of interest

The authors have no conflicts of interest.

Funding/support

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sections.

Authors' contributions

CA and YP were involved in study conception and design. All authors performed test procedures and data acquisition. CA, YS, and SM performed the data analysis and/or interpretation. CA wrote the first draft the manuscript and CA and YS revised the manuscript critically for important intellectual concept. All authors have given final approval of the version to be published.

Acknowledgements

The authors would like to thank all the participants in this study.

References

[1] Esquenzi A, Hirai B. Assessment of gait and orthotic prescription. Phys Med Rehab Clin North Am 1991;2:473–85.
[2] Tilson JK, Settle SM, Sullivan KJ. Application of evidence-based practice strategies: Current trends in walking recovery interventions poststroke. Top Stroke Rehabil 2008;15:227–46.
[3] Latham NK, Jette DU, Slavin M, Richards LG, Procino A, Smout RJ, et al. Physical therapy during stroke rehabilitation for people with different walking abilities. Arch Phys Med Rehabil 2005;8:41–50.
[4] Hsu AL, Tang PF, Jan MH. Analysis of impairments influencing gait velocity and asymmetry of hemiplegic patients after mild to moderate stroke. Arch Phys Med Rehabil 2003;84:1185–93.
[5] de Haart M, Geurts AC, Huidekoper SC, Fasotti L, van Limbeek J. Recovery of standing balance in postacute stroke patients: a rehabilitation cohort study. Arch Phys Med Rehabil 2004;85:886–95.
[6] Jørgensen L, Crabtree NJ, Reeve J, Jacobsen BK. Ambulatory level and asymmetrical weight bearing after stroke affects bone loss in the upper and lower part of the femoral neck differently: bone adaptation after decreased mechanical loading. Bone 2000;27:701–7.
[7] Patterson KK, Gage WH, Brooks D, Black SE, McIlroy WE. Evaluation of gait symmetry after stroke: a comparison of current methods and recommendations for standardization. Gait Posture 2010;31:241–6.
[8] Ellis RG, Howard KC, Kram R. The metabolic and mechanical costs of step time asymmetry in walking. Proc Biol Sci 2013;280:20122784.
[9] Balasubramanian CK, Neptune RR, Kautz SA. Foot placement in a body reference frame during walking and its relationship to hemiparetic walking performance. Clin Biomech 2010;25:483–90.
[10] Lin PY, Yang YR, Cheng SJ, Wang RY. The relation between ankle impairments and gait velocity and symmetry in people with stroke. Arch Phys Med Rehabil 2006;87:562–8.
[11] Nardone A, Godi M, Grasso M, Guglielmetti S, Schieppati M. Stabilometry is a predictor of gait performance in chronic hemiparetic stroke patients. Gait Posture 2009;30:5–10.
[12] Hendrickson J, Patterson KK, Inness EL, McIlroy WE, Mansfield A. Relationship between asymmetry of quiet standing balance control and walking post-stroke. Gait Posture 2014;39:177–81.
[13] Lewek MD, Bradley CE, Wutzke CJ, Zinder SM. The relationship between spatiotemporal gait asymmetry and balance in individuals with chronic stroke. J Appl Biomech 2014;30:31–6.
[14] Grasso R, Zago M, Lacquaniti F. Interactions between posture and locomotion: motor patterns in humans walking with bent posture versus erect posture. J Neurophysiol 2000;83:288–300.
[15] Biodex Balance System SD. Operation and service manual 950-441. Shirly, New York: Biodex Medical System; 2010.

[16] Barra J, Oujamaa L, Chauvineau V, Rougier P, Pérennou D. Asymmetric standing posture after stroke is related to a biased egocentric coordinate system. Neurology 2009;72:1582—7.
[17] Patterson KK, Mansfield A, Biasin L, Brunton K, Inness EL, McIlroy WE. Longitudinal changes in poststroke spatiotemporal gait asymmetry over inpatient rehabilitation. Neurorehabil Neural Repair 2015;29:153—62.
[18] Orendurff MS, Segal AD, Klute GK, Berge JS, Rohr ES, Kadel NJ. The effect of walking speed on center of mass displacement. J Rehabil Res Dev 2004;41:829—34.
[19] Chen G, Patten C, Kothari DH, Zajac FE. Gait differences between individuals with post-stroke hemiparesis and non-disabled controls at matched speeds. Gait Posture 2005;22:51—6.
[20] Balasubramanian CK, Bowden MG, Neptune RR, Kautz SA. Relationship between step length asymmetry and walking performance in subjects with chronic hemiparesis. Arch Phys Med Rehabil 2007;88:43—9.
[21] Perry J, Burnfield J. Gait Analysis: Normal and pathological function. 2nd ed. California: Slack; 2010.
[22] Alexander LD, Black SE, Patterson KK, Gao F, Danells CJ, McIlroy WE. Association between gait asymmetry and brain lesion location in stroke patients. Stroke 2009;40:537—44.
[23] Lin SI. Motor function and joint position sense in relation to gait performance in chronic stroke patients. Arch Phys Med Rehabil 2005;86:197—203.