The contributions of balance to gait capacity and motor function in chronic stroke

KYOUNG BO LEE, PT, PhD1), SEONG HOON LIM, MD, PhD2), YOUNG DONG KIM, PT, PhD3), BYUNG IL YANG, PT, MPT4), KYOUNG HOON KIM, PT, MPT5), KANG SUNG LEE, PT, PhD, CPO6), EUN JA KIM, PT, PhD7), BYONG YONG HWANG, PT, PhD8)*

1) Department of Physical Therapy, St. Vincent Hospital, Republic of Korea
2) Department of Rehabilitation Medicine, St. Vincent Hospital, Republic of Korea
3) Department of Physical Therapy, Sungsim Rehabilitation Hospital, Republic of Korea
4) Department of Physical Therapy, Bobath Memorial Hospital, Republic of Korea
5) Department of Physical Therapy, Sahmyook University, Republic of Korea
6) Department of Prosthetics and Orthotics, Hanseo University, Republic of Korea
7) Department of Physical Therapy, Kyungdong University, Republic of Korea
8) Department of Physical Therapy, Yongin University: 470 Samsan-dong, Cheoin-gu, Yongin-si, Gyeonggi-do 449-714, Republic of Korea

Abstract. [Purpose] The aim of this study was to identify the contributions of balance to gait and motor function in chronic stroke. [Subjects and Methods] Twenty-three outpatients participated in a cross-sectional assessment. Gait ability was assessed using the functional ambulation category, self-paced 10-m walking speed, and fastest 10-m walking speed. Standing balance and trunk control measures included the Berg Balance Scale and the Trunk Impairment Scale. Univariate and multivariate regression analyses were performed. [Results] Balance was the best predictor of the FAC, self-paced walking speed, and fastest walking speed, accounting for 57% to 61% of the variances. Additionally, the total score of TIS was the only predictor of the motor function of the lower limbs and the dynamic balance of TIS was a predictor of the motor function of the upper limbs, accounting for 41% and 29% of the variances, respectively. [Conclusion] This study demonstrated the relative contribution of standing balance and trunk balance to gait ability and motor function. They show that balance has a high power of explanation of gait ability and that trunk balance is a determinant of motor function rather than gait ability.

Key words: Chronic stroke, Gait, Balance

INTRODUCTION

Studies of factors related to impairments specific to gait or functional activity have targeted appropriate strategies for gait rehabilitation, and much of this research has been done in a clinical environment1–4, examining gait rehabilitation based on the impairments of stroke patients5, 6).

Three factors affect the ability to walk: limb stability, balance, and limb advancement3). Of these, balance has been widely evaluated in stroke rehabilitation. There is a positive correlation between standing balance and gait velocity1–3, 7). Although there is a significant relationship between balance and gait, little is known about how the muscle strength of the affected leg affects gait ability3) and there might be compensatory movement rather than true impairment recovery following a stroke.

Trunk control is an early predictor of daily living activities following a stroke. The recovery of trunk performance may range from 45–71%9–12). The abnormal pelvic displacement of stroke patients impairs their balance ability and decreases...
their gait speed\(^3\)). Until now, most research addressing the effects of treatment on performance has focused on the legs and arms, rather than trunk performance, and the recovery of trunk balance has been ignored in rehabilitation research\(^4, 5\). In addition, little is known about the relationship between motor recovery and trunk control.

Of the methods used to evaluate walking ability, gait speed is the most sensitive measure. The requirements for self-paced walking speed or fastest walking speed can depend on the environment, and gait speed influences the temporal and spatial gait characteristics of hemiplegic stroke patients\(^6\). An inability to walk quickly is an important functional limitation. To improve gait ability, therapeutic treatments typically focus on muscle strength, balance, motor function, sensory impairment, and spasticity\(^6, 7\).

To maximize the treatment effectiveness, physical therapy need to be evidence-based and should focus on specific stroke components or impairments in the intervention. Although research has analyzed factors related to gait ability, the relative importance of standing balance and trunk balance in walking and motor function has not been established. The most important rehabilitation goal is the recovery of independent, safe, quick, and long distance gait\(^5\). Therefore, the improvement of gait speed is a major goal in stroke rehabilitation\(^8\) and investigation of factors related to impairments specific to activity limitations may be helpful for determining and targeting appropriate strategies for gait rehabilitation. Therefore, this study investigated the contributions of balance to gait and motor function in chronic stroke.

**SUBJECTS AND METHODS**

We conducted a cross-sectional assessment of outpatients treated for stroke at St. Vincent’s Hospital, Suwon, Republic of Korea. Exclusion criteria were bilateral lesions, brainstem lesions, orthopedic problems leading to difficulty with balance and gait, and comprehension problems. This study followed the principles of the Declaration of Helsinki, and all patients gave their informed consent.

Two therapists conducted the tests. To control the inter-rater reliability of the measurements, one evaluated impairments using the Trunk Impairment Scale (TIS)\(^9\), Berg Balance Scale (BBS)\(^10\), and Fugl-Meyer motor assessment of the upper and lower extremities\(^11\), and the other measured gait ability using the Functional Ambulatory Category (FAC), and the self-paced 10-m walking speed, and fastest 10-m walking speed. The subjects asked to walk at a self-paced speed and as quickly as possible and their walking times were measured over the middle 10 m of a 15-m pathway. Two trials of each walking speed were performed, and the mean time of the two was used in the analysis.

Univariate regression analysis was performed to identify relationships between gait ability and the TIS score, TIS subscores, and BBS. Variables in the univariate analyses with p < 0.15 were included as independent variables in the multivariate regression analysis. Significance was accepted for values of p < 0.05.

**RESULTS**

This study enrolled 23 patients with a mean age of 51.4 ± 12.7 (range 20–71) years. Table 1 summarizes the assessment results. The mean self-paced and fastest walking speeds were 0.69 and 0.86 m/s, respectively. In the univariate regression model, the total TIS and TIS subscores were significantly related to gait ability and motor function, and a significant relationship was found between the TIS static balance subscale and self-paced walking speed. The TIS dynamic balance subscale and BBS were significantly related to gait ability and motor function. The TIS coordination subscale was related to the FAC and motor function of the lower limbs (Table 2). In the multivariate regression model, balance was the best predictor of the FAC, self-paced walking speed, and fastest walking speed, accounting for 57–61% of the variances. The total TIS score was the only predictor of the motor function of the lower limbs, and the TIS dynamic balance subscale predicted the motor function of the upper limbs, accounting for 41% and 29% of the variance, respectively (Table 3).

**DISCUSSION**

This study investigated the relative contributions of standing balance and trunk balance to gait ability and motor function. The results verify the contribution of standing balance to gait ability and are in agreement with the findings of previous studies\(^1, 8\). A significant relationship was demonstrated between balance and gait. Katz-Leurer et al. suggested that the strategy for reducing gait speed might reflect adaptations needed to increase stability during walking by children with traumatic brain injury\(^4\). There was a weak relationship between muscle strength of the affected leg and gait ability, which might be due to compensatory movement rather than to true recovery of impairment following stroke\(^5\).

The relationship between balance and walking in stroke patients has been highlighted\(^7\). Previously, we demonstrated that balance is an important factor in gait speed and distance in multiple regression analysis\(^9\). In the present study, the BBS was the only contributor to the FAC level and self-paced and fastest walking speeds. Trunk balance was not a significant predictor of gait ability. This might be because the BBS consists of 14 items involving various tasks performed while sitting and standing, and measures different aspects of postural control other than balance control while sitting. The TIS is more strongly related to measures of motor function than the gait ability of stroke patients. In our recent study, the similar degrees of recovery observed in the trunk and lower leg support this proposition\(^2, 3\).
In the present study, although balance had a high power of explaining gait ability, trunk balance was a determinant of motor function rather than gait ability. Based on the evidence of bilateral innervation of the trunk musculature\textsuperscript{23}, recovery of trunk control after stroke may be likely. However, the results of this study indicate that trunk performance is impaired in chronic stroke patients, supporting the findings of Verheyden et al.\textsuperscript{24, 25}. There is evidence that trunk performance is an important predictor of functional outcome following stroke\textsuperscript{9–11}. Verheyden et al. found relationships between trunk performance and measures of balance, gait, and functional ability after stroke\textsuperscript{24}. In our study, no subject received the maximum score on the trunk impairment scale, indicating that the measure has no ceiling effect, and Verheyden et al. suggested that a score greater than 20 is indicative of normal trunk function\textsuperscript{12}. Dynamic sitting balance and co-ordination are indicators of the ability to perform lateral flexion and rotation of the upper and lower parts of the trunk, respectively. This might explain why the result of the regression analysis between the total TIS and lower motor function was significant, as was the relationship between dynamic sitting balance and upper motor function.

Table 1. Trunk balance, balance, motor function, and gait parameters of the participants

| Variables | Median (IQR) | Range |
|-----------|-------------|-------|
| TIS total (0–23) | 16 (12–18) | 9–22 |
| Static sitting balance (0–7) | 7 (6–7) | 4–7 |
| Dynamic sitting balance (0–10) | 7 (4–9) | 2–10 |
| Co-ordination (0–6) | 2 (1–4) | 0–5 |
| Fugl-Meyer Assessment (Total) | | |
| Upper limb (0–66) | 17 (12–24) | 6–58 |
| Lower limb (0–34) | 19 (17–20) | 10–26 |
| Berg Balance Scale (0–56) | 49 (41–51) | 26–55 |
| Functional Ambulation Category (0–5) | 5 (4–5) | 3–5 |
| Self-paced 10-m walk speed (m/s) | 0.69 ± 0.30\textsuperscript{*} | 0.16–1.08 |
| Fastest 10-m walk speed (m/s) | 0.86 ± 0.39\textsuperscript{*} | 0.22–1.50 |

\textsuperscript{*}Mean ± SD

Table 2. Univariate regression analysis of trunk balance, standing balance, motor function, and gait ability

| Univariate regression analysis | Static TIS | Dynamic TIS | Co-ordination TIS | Total TIS | BBS |
|-------------------------------|------------|-------------|-------------------|-----------|-----|
| FAC                           | 0.046      | 0.209 *     | 0.217 *           | 0.258 *   | 0.577 ** |
| Self-paced 10 MWT             | 0.194 *    | 0.268 *     | 0.151             | 0.321 **  | 0.613 ** |
| Fastest 10 MWT                | 0.126      | 0.200 *     | 0.072             | 0.211 *   | 0.598 ** |
| FMA-total                     | 0.122      | 0.403 **    | 0.192 *           | 0.411 **  | 0.375 ** |
| FMA-lower                     | 0.022      | 0.290 **    | 0.019             | 0.185 *   | 0.210 * |
| FMA-upper                     | 0.290 **   | 0.411 **    | 0.411             | 0.290     |     |

FMA: Fugl-Meyer Assessment; 10 MWT: 10-m walk time; FAC: functional ambulation category. Values are presented as R\textsuperscript{2}. *p<0.05, **p<0.01

Table 3. Multivariate regression analysis using trunk balance and BBS as explanatory variables of motor function and gait ability

| Multivariate regression analysis | Static TIS | Dynamic TIS | Co-ordination TIS | Total TIS | BBS | Model R\textsuperscript{2} |
|---------------------------------|------------|-------------|-------------------|-----------|-----|---------------------------|
| FAC                             |            | 0.577 **    |                   | 0.577     |     |                           |
| Self-paced 10 MWT               |            | 0.613 **    |                   | 0.613     |     |                           |
| Fastest 10 MWT                  |            |             |                   |           |     |                           |
| FMA-total                       |            | 0.598 **    |                   | 0.598     |     |                           |
| FMA-lower                       |            | 0.411 **    |                   | 0.411     |     |                           |
| FMA-upper                       | 0.290 **   |             |                   |           |     |                           |

FMA: Fugl-Meyer Assessment; 10 MWT: 10-m walk time; FAC: functional ambulation category. Values are presented as R\textsuperscript{2}. *p<0.05, **p<0.01
Although gait speed is a sensitive measure of objective changes in walking\textsuperscript{26} and a reliable tool for stroke patients\textsuperscript{27}, there was no significant relationship between the improvement in gait speed and motor function\textsuperscript{28}. Gait speed could not be explained completely by balance in our series. Muscle strength and spasticity were considered contributors to gait speed in another study\textsuperscript{3}. Therefore, we also used the FAC to evaluate gait ability. The FAC was designed to provide information on the level of physical support needed by patients to ambulate both outdoors and indoors. The assessment is scored from 0 (requiring continuous support from two individuals) to 5 (ability to walk indoors and outdoors independently)\textsuperscript{29}. Nevertheless, only BBS explained FAC, implying that balance is a very important factor for ambulation outdoors.

Our results must be interpreted with caution, because the sample size in this trial was small. Moreover, the measures of gait ability and motor recovery were compared only with the BBS and TIS. As ambulation is a complex cooperative movement involving the motor, sensory, and cognitive systems, other factors related to walking ability following a stroke need to be considered. A prospective study of acute stroke patients is necessary to analyze the relationship between change in balance and walking recovery, as well as to determine the actual activity of the trunk and the extremities’ musculature during a task using electromyography. In addition, further studies of effective training are needed to better understand whether standing balance and trunk balance exercises enhance the gait ability and motor functions of patients with chronic stroke.

REFERENCES

1) 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: 1185–1193. [Medline] [CrossRef]
2) Keenan MA, Perry J, Jordan C: Factors affecting balance and ambulation following stroke. Clin Orthop Relat Res, 1984, (182): 165–171. [Medline]
3) Lee KB, Lim SH, Ko EH, et al.: Factors related to community ambulation in patients with chronic stroke. Top Stroke Rehabil, 2015, 22: 63–71. [Medline] [CrossRef]
4) Katz-Leurer M, Rotem H, Lewitus H, et al.: Relationship between balance abilities and gait characteristics in children with post-traumatic brain injury. Brain Inj, 2008, 22: 153–159. [Medline] [CrossRef]
5) Hesse S: Gait training after stroke: a critical reprisal. Ann Readapt Med Phys, 2006, 49: 621–624. [Medline] [CrossRef]
6) Rodriguez AA, Black PO, Kile KA, et al.: Gait training efficacy using a home-based practice model in chronic hemiplegia. Arch Phys Med Rehabil, 1996, 77: 801–805. [Medline] [CrossRef]
7) Michael KM, Allen JK, Macko RF: Reduced ambulatory activity after stroke: the role of balance, gait, and cardiovascular fitness. Arch Phys Med Rehabil, 2005, 86: 1552–1556. [Medline] [CrossRef]
8) Kollen B, van de Port I, Lindeman E, et al.: Predicting improvement in gait after stroke: a longitudinal prospective study. Stroke, 2005, 36: 2676–2680. [Medline] [CrossRef]
9) Hsieh CL, Sheu CF, Hsieh IP, et al.: Trunk control as an early predictor of comprehensive activities of daily living function in stroke patients. Stroke, 2002, 33: 2626–2630. [Medline] [CrossRef]
10) Duarte E, Marco E, Muniesa JM, et al.: Trunk control test as a functional predictor in stroke patients. J Rehabil Med, 2002, 34: 267–272. [Medline] [CrossRef]
11) Franchignoni FP, Tesio L, Ricupero C, et al.: Trunk control test as an early predictor of stroke rehabilitation outcome. Stroke, 1997, 28: 1382–1385. [Medline] [CrossRef]
12) Verheyden G, Nieuwboer A, Feys H, et al.: Discriminant ability of the Trunk Impairment Scale: a comparison between stroke patients and healthy individuals. Disabil Rehabil, 2005, 27: 1023–1028. [Medline] [CrossRef]
13) Kong SW, Jeong YW, Kim JY: Correlation between balance and gait according to pelvic displacement in stroke patients. J Phys Ther Sci, 2015, 27: 2171–2174. [Medline] [CrossRef]
14) Verheyden G, Nieuwboer A, Van de Winckel A, et al.: Clinical tools to measure trunk performance after stroke: a systematic review of the literature. Clin Rehabil, 2007, 21: 387–394. [Medline] [CrossRef]
15) Lee KB, Kim JH, Lee KS: The relationship between motor recovery and gait velocity during dual tasks in patients with chronic stroke. J Phys Ther Sci, 2015, 27: 1173–1176. [Medline] [CrossRef]
16) You YY, Chung SH: The effects of gait velocity on the gait characteristics of hemiplegic patients. J Phys Ther Sci, 2015, 27: 921–924. [Medline] [CrossRef]
17) Sharp SA, Brouwer BF: Isokinetic strength training of the hemiparetic knee: effects on function and spasticity. Arch Phys Med Rehabil, 1997, 78: 1231–1236. [Medline] [CrossRef]
18) Canning CG, Ada L, Paul SS: Is automaticity of walking regained after stroke? Disabil Rehabil, 2006, 28: 97–102. [Medline] [CrossRef]
19) Verheyden G, Nieuwboer A, Merrin J, et al.: The Trunk Impairment Scale: a new tool to measure motor impairment of the trunk after stroke. Clin Rehabil, 2004, 18: 326–334. [Medline] [CrossRef]
20) Berg K, Wood-Dauphinee S, Williams JF: The Balance Scale: reliability assessment with elderly residents and patients with an acute stroke. Scand J Rehabil Med, 1995, 27: 27–36. [Medline] [CrossRef]
21) Fugi-Meyer AR, Jääskö L, Leyman I, et al.: The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. Scand J Rehabil Med, 1975, 7: 13–31. [Medline]
22) Lee KB, Lim SH, Kim KH, et al.: Six-month functional recovery of stroke patients: a multi-time-point study. Int J Rehabil Res, 2015, 38: 173–180. [Medline] [CrossRef]
23) Carr LJ, Harrison LM, Stephens JA: Evidence for bilateral innervation of certain homologous motoneurone pools in man. J Physiol, 1994, 475: 217–227. [Medline] [CrossRef]
24) Verheyden G, Vereeck L, Truijen S, et al.: Trunk performance after stroke and the relationship with balance, gait and functional ability. Clin Rehabil, 2006, 20: 451–458. [Medline] [CrossRef]
25) Liao CF, Liaw LJ, Wang RY, et al.: Relationship between trunk stability during voluntary limb and trunk movements and clinical measurements of patients with chronic stroke. J Phys Ther Sci, 2015, 27: 2201–2206. [Medline] [CrossRef]

26) Kollen B, Kwakkel G, Lindeman E: Time dependency of walking classification in stroke. Phys Ther, 2006, 86: 618–625. [Medline]

27) Wade DT, Wood VA, Heller A, et al.: Walking after stroke. Measurement and recovery over the first 3 months. Scand J Rehabil Med, 1987, 19: 25–30. [Medline]

28) Duncan P, Studenski S, Richards L, et al.: Randomized clinical trial of therapeutic exercise in subacute stroke. Stroke, 2003, 34: 2173–2180. [Medline] [CrossRef]

29) Holden MK, Gill KM, Magliozzi MR: Gait assessment for neurologically impaired patients. Standards for outcome assessment. Phys Ther, 1986, 66: 1530–1539. [Medline]