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Original Article

Key function for obstacle crossing in hemiplegic persons with varied degrees of spasticity

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Abstract. [Purpose] To evaluate various key functions related to obstacle crossing motions in hemiplegic people based on the paralysis degree. [Subjects and Methods] Thirty-seven patients with maintenance-stage hemiplegia who could independently ambulate outdoors were included. Subjects' crossing movements were measured using obstacles with heights of 10%, 20%, and 30% of the trochanter length. The relationship among maximal crossing height and isometric knee extension muscle strength, one leg standing time, Trunk Impairment Scale score, disease duration, and subject age was examined, as was the target variable of maximum crossing height and the top four measurement items, to determine the explanatory variables. The participants were grouped based on Brunnstrom Recovery Stages III–IV (severe spasticity) and V–VI (mild spasticity). [Results] The explanatory variables were the Trunk Impairment Scale in the severe spasticity group and unaffected side-knee extension muscle strength in the mild spasticity group (contribution rates: 75.6% and 21.0%, respectively). [Conclusion] Trunk function in the severe spasticity group majorly contributed to crossing obstacles. Furthermore, knee extension muscle strength on the unaffected side in the mild spasticity group moderately contributed to crossing obstacles. Selecting and implementing a physical therapy routine that is aimed at improving function, depending on the severity of paralysis, is necessary.

Key words: Hemiplegia, Obstacle crossing, Key function

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INTRODUCTION

Obstacle crossing such as walking across doorway thresholds and cords or stepping over sidewalk curbs and snow melting equipment on the street is a necessary part of daily activities. However, obstacle crossing is difficult for patients who present with hemiplegia due to stroke, even after the patient is able to ambulate without assistance[1)]. We prepared an obstacle for our physical therapy program for people with hemiplegia in order to simulate the height and depth of objects that are encountered in everyday life and to assist patients in navigating these obstacles.

The ability to perform obstacle crossing movements is also associated with falling. A history of stroke has been said to be a risk factor for falling[2)], and it can reduce obstacle crossing ability. According to Said et al.[3)], stroke patients who touch obstacles while striding or those who lose their balance have an approximately 6 times greater chance of falling than those who do not. Therefore, it is important to provide instructional guidance that is designed to aid hemiplegic patients in safely

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Table 1. Subject characteristics

		BRS III	BRS IV	BRS V	BRS VI
No. of cases		13	6	15	3
Gender (cases)	Males	8	2	12	3
	Females	5	4	3	0
Age (years)		69.6 ± 7.0	66.8 ± 6.0	66.7 ± 6.0	67.7 ± 2.3
Poststroke duration (months)		153.9 ± 180.0	65.4 ± 75.9	204.5 ± 183.2	124.2 ± 90.5
Height (cm)		158.5 ± 5.2	156.8 ± 5.5	161.7 ± 2.5	162.7 ± 1.5
Weight (kg)		52.6 ± 7.2	52.5 ± 8.1	58.8 ± 5.6	60.8 ± 1.5
Affected side (cases)	Right	4	2	9	3
	Left	9	4	6	0
Gait type (cases)	Cane	3	4	0	0
	Cane + brace	10	2	0	0
	Ind. walking	0	0	15	3

BRS: Brunnstrom recovery stage

performing obstacle crossing. We conducted several studies in order to evaluate different methods of crossing obstacles4–8). By comparing obstacle crossing that is initiated from the affected side (affected lead limb) and the unaffected side (unaffected lead limb), we found that the affected lead limb motion was easier to perform than that for the unaffected lead limb4). Analysis of obstacle crossing with a gait analysis system revealed that as the obstacle's height increased, lower limb swing time during the second step to traverse the obstacle increased in healthy subjects5). In contrast, for hemiplegic subjects, the swing time of the affected lead limb during obstacle crossing extended as the obstacle's height increased, while the swing time of the unaffected leg during the second traversing step shortened5). Hemiplegic patients have also acknowledged that they have shorter step width5) and that they perform obstacle crossing differently than healthy people. This is believed to be the effect of hemiplegic patients' effort to avoid contact between affected toes and obstacles; indeed, compared with healthy subjects, hemiplegics increased the amount of clearance between obstacles and toes while crossing obstacles6).

We also focused on instances in the daily lives of hemiplegic people in which they would need to cross obstacles, and we assessed safer methods for crossing obstacles and strengthening necessary physical functions. The physical functions that are important for hemiplegic patients to cross higher obstacles are lower limb muscle strength, walking speed, and affected side load ratio7), as well as trunk function and unaffected knee extension muscle strength8). Among these functions, lower limb muscle strength, which supports muscle function on the affected side, and trunk function have each been demonstrated to be important for improving the walking ability of hemiplegic patients9–14).

We have not previously analyzed the function related to physical functions that are important in obstacle crossing movements based on the degree of the severity of paralysis. Other studies that assessed gait in patients with hemiplegia15, 16) have reported that lower limb joint motion asymmetry during gait is influenced by the severity of paralysis. Based on this observation, it is possible that the functions that are important during obstacle crossing movements in people with hemiplegia may differ based on whether obstacles are crossed adequately or inadequately.

Therefore, we studied the severity of paralysis in patients with hemiplegia to evaluate how the functions that are important for crossing obstacles differ among each other.

SUBJECTS AND METHODS

This study enrolled 37 subjects (25 males and 12 females) presenting with maintenance-stage hemiplegia who were capable of independent, outdoor ambulation. The mean age of the participants was 67.8 ± 7.0 years, the average duration of disease from onset was 158 ± 166 months, the average height was 159.9 ± 4.5 cm, and the average weight was 55.8 ± 7.1 kg. Eighteen subjects were affected on the right side, and 19 subjects were affected on the left side. Because the study population was limited to patients with hemiplegia with independent ambulation outdoors, no subjects exhibited a lower limb Brunnstrom Recovery Stage (BRS) below II. Of the walking styles observed, 18 subjects walked fully independently, seven subjects walked with the aid of a cane, and 12 subjects walked with the aid of a cane and brace. Nineteen patients used canes or brace to walk, although they were fully capable of walking independently. Table 1 displays the baseline characteristics of the patients, categorized by BRS. Subjects with severe sensory disorders or acute orthopedic diseases were excluded from study enrollment. All subjects were fully briefed regarding the purpose and nature of this study prior to participation in accordance with ethical obligations, and the oral and written consent of all subjects was obtained. This study was conducted after obtaining approval from the Ethics Committee of Keiju Medical Center (review number: 17-1).

The obstacle crossing exercises were measured indoors. A strip of paper tape was set up as an obstacle in the center of a 5 m walkway, and subjects crossed the obstacle according to the method applied in our prior study8) (Fig. 1). Free spaces that were 3 m in length were set before and after the 5 m walk way. Subjects walked freely and independently in these spaces. Subjects using canes or brace were also deemed to be walking independently.

Based on the results of our previous study4), we presumed that patients with hemiplegia would perform obstacle-crossing

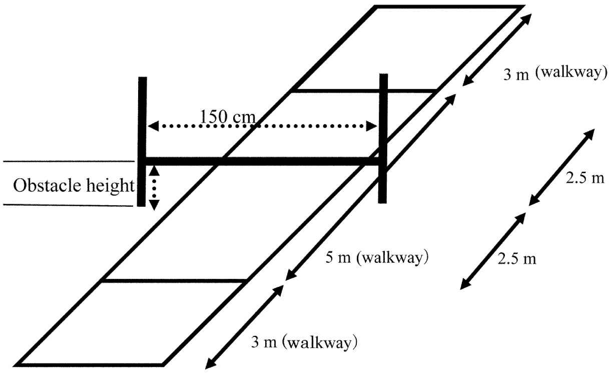

Fig. 1. Obstacle crossing movement measurement set-up
A strip of paper tape was set up on the 5 m walkway as an obstacle. Free spaces that were 3 m in length were set before and after the 5 m walk way.

movements with the affected lead limb more easily than with the unaffected lead limb. The measurer observed the patients from the side and considered their risk of falling. The height of the obstacle was set at three different heights: 10%, 20%, and 30% of each subject's trochanter malleolar distance8). This test was conducted once using affected lead limb obstacle crossing. The order by which the height of the obstacle was set was randomized, and whether or not subjects contacted the obstacle was also recorded. The highest obstacle that could be traversed without making contact was recorded as the measurement value (maximum height [%] obstacle crossed).

Important functions included those used in previous studies related to walking ability9–14), as well as those frequently used clinically and that require only brief examination periods. Muscle strength was measured using the Combit CB-1 isometric muscle force measurement device (Minato Medical Science Co., Ltd., Osaka, Japan), and isometric extension force (knee extension muscle strength) in the contracted position was measured once for 5 s on both the left and right sides. The value that was obtained by dividing the measured value by the subject's body weight (Nm/kg) was used. The one-leg position standing time (one-leg standing position) was measured once for each leg, with the patient keeping both eyes open. The Trunk Impairment Scale (TIS) was used to evaluate trunk function17). The TIS is comprised of three subscales that evaluate trunk rotation: Static Sitting Balance, Dynamic Sitting Balance, and Co-ordination, which examine lateral bending of the trunk. Each test was performed once.

For statistical analysis, SPSS Statistics Ver. 23.0 (IBM, Cary, NC, USA) software was used. To investigate if each of the lower limbs exhibited isolated movement to determine the functions that were important in obstacle crossing, we divided subjects into the BRS III–IV and BRS V–VI groups. Subjects in the BRS III–IV group exhibited difficulty isolating lower limb movement, while subjects in the BRS V–VI group were able to isolate this movement. Relationships between maximum obstacle crossing height in each group, subject age, disease period, affected-side knee extension muscle strength, unaffected-side knee extension muscle strength, one-leg standing position on the affected side, one-leg standing position on the unaffected side, and total TIS score were each assessed through a single regression analysis. The function affecting maximum obstacle crossing height were extracted by conducting a multiple regression analysis of the maximum obstacle height and the four items that were extracted through the previous single regression analyses using the stepwise method, and the highest coefficient of determination R^2 was selected as the explanatory variable. The level of significance for all analyses was $p<0.05$.

RESULTS

The average values for each measurement item in the BRS III–IV and BRS V–VI groups are displayed in Table 2. Twenty-one subjects (five with BRS III–IV and 16 with BRS V–VI) exhibited a maximum height of 30%, 32 subjects (14 with BRS III–IV and 18 with BRS V–VI) exhibited a maximum height of 20%, 36 subjects (18 with BRS III–IV: and 18 with BRS V–VI) exhibited a maximum height of 10%, and one subject (with BRS III) exhibited an obstacle height of 0 (i.e., the subject did not demonstrate any of the three obstacle crossing heights). In the single regression analysis of the relationship between the maximum obstacle height and each measurement item, one-leg standing position on the affected side, one-leg standing position on the unaffected side, and total TIS score in the BRS III–IV group exhibited a linear regression (Table 3). No significant regression was observed for the other measurement items. In the BRS V–VI group, only unaffected-side knee extension muscle strength was displayed in the linear regression (Table 3). As a result of the multiple regression analysis that was conducted using the stepwise method and the top four measurement items that were extracted as explanatory variables through the single regression analysis, TIS was selected as the explanatory variable for the BRS III–IV group ($p<0.001$), and its contribution rate was 75.6% (Table 4). In the BRS V–VI group, unaffected knee extension muscle strength was chosen as the explanatory variable ($p<0.05$), and its contribution rate was 21.0%.

Table 2. Comparison of each measurement value between the BRS III–IV groups and BRS V–VI groups

		BRS III–IV	BRS V–VI
Obstacle height (cm)		13.4 ± 5.8	21.0 ± 2.5
Knee extension muscle strength on affected side (Nm/kg)		0.49 ± 0.32	1.14 ± 0.22
Knee extension muscle strength on unaffected side (Nm/kg)		1.29 ± 0.44	2.16 ± 0.38
One-leg standing time on affected side (seconds)		0.62 ± 0.49	11.03 ± 13.80
One-leg standing time on unaffected side (seconds)		5.18 ± 8.03	41.93 ± 27.14
TIS (score)	Total	15.0 ± 2.5	21.2 ± 1.7
	SSB	7.0 ± 0.0	7.0 ± 0.0
	DSB	5.2 ± 2.1	9.4 ± 1.0
	COO	2.8 ± 0.8	4.8 ± 1.0

Mean value ± standard deviation
TIS: Trunk impairment scale; SSB: Static sitting balance; DSB: Dynamic sitting balance; COO: Co-ordination

Table 3. Single regression analysis of maximum obstacle crossing height and each measurement item

	Determination coefficient (R^2)	
	BRS III–IV	BRS V–VI
Age	0.057	0.044
Disease period	0.053	0.133
Knee extension muscle strength on affected side	0.150	0.127
Knee extension muscle strength on unaffected side	0.170	0.257*
One-leg standing time on affected side	0.526**	0.045
One-leg standing time on unaffected side	0.365**	0.075
TIS	0.770**	0.005

TIS: Trunk impairment scale
*$p<0.05$, **$p<0.01$

Table 4. Results of multiple regression analysis

Item	Estimate	Standard error	Standard β	p-value
TIS (BRS III–IV)	3.024	0.401	0.877	0.0001
Knee extension muscle strength on unaffected side (BRS V–VI)	4.343	1.847	0.507	0.0318

Estimation formula
Obstacle height (%)=−25.729 + 3.024 × TIS
$p<0.001$, contribution ratio 75.6%
Obstacle height (%)=19.498 + 4.343 × Knee extension muscle strength on unaffected side
$p<0.05$, contribution ratio 21.0%

DISCUSSION

After separately examining participants based on whether they exhibited affected-side lead obstacle crossing, we found that trunk function contributed to obstacle crossing height in the BRS III–IV group. In the BRS V–VI group, knee extension strength on the unaffected side moderately contributed. These results indicate that the functions that were important for obstacle crossing movements by patients with hemiplegia differed depending on whether movement of the affected limb could be isolated.

Next, we considered the selection of the TIS score for evaluating participants in the BRS III–IV group. In previous studies[1, 18)], when patients with hemiplegia traversed obstacles, they employed an obstacle crossing method that widened the angle of the lower limb joints, particularly that of the hip joint. However, in our study, because subjects in the BRS III–IV group demonstrated insufficient ability to isolate their movements and inadequate movement support, they experienced difficulty when crossing obstacles due to the wider angle of their lower limb joints, and there was a strong possibility that these subjects bent and rotated their trunks more when crossing obstacles while swinging their affected limb. In addition, these subjects' affected side offered little support to the unaffected leg while striding. Based on these observations, we selected the

TIS score, which is an indicator of trunk function, for the BRS III–IV group, considering the apparent role of the trunk in compensating for lost lower limb function.

Knee extension muscle strength on the unaffected side was selected as a factor that influenced the height of obstacles that could be crossed by subjects in the BRS V–VI group. Lee et al.[19] found that as the height of obstacles that were crossed by patients with hemiplegia increases, stance time on the unaffected side also increases. Although multiple functions contribute to the support capacity of the standing position[20–24], with lower limb muscle strength as a single example, the corresponding factor measured in this study was knee extension muscle strength. We selected knee extension muscle strength on the unaffected side as the pertinent factor for subjects in the BRS V–VI group based on our conclusion that this factor should reflect the support function of the unaffected limb.

Trunk function was not selected as a factor for subjects in the BRS V–VI group. Said et al.[1] found that patients with hemiplegia often bend their hip joints as a strategy to traverse obstacles. This was because patients in the BRS V–VI group derived greater support from their affected limb than patients in the BRS III–IV group did. We believe that these subjects were able to cross obstacles by widening their hip and knee joint angles while swinging the unaffected limb forward from the rear. Additionally, isolated movements in the BRS V–VI group differed from the insufficient movements demonstrated by subjects in the BRS III–IV group, and we theorize that subjects in the BRS V–VI group were capable of performing isolated lower limb joint movements and obstacle crossing, similar to healthy people. We thought that these movements could be performed without compensation for trunk function. We believe that these subjects should be able to complete the obstacle crossing movement without the need for compensation from the trunk; therefore, this factor was selected during statistical analysis.

In our previous study[8] of patients with BRS III–V hemiplegia, TIS score and unaffected knee extension muscle strength were important functions, whereas in this study, in which subjects were grouped according to the severity of paralysis, the important functions were trunk function in the BRS III–IV group and unaffected knee extension muscle strength in the BRS V–VI group. These results suggest that it is necessary to select and implement a physical therapy routine that is aimed at improving function, depending on the severity of paralysis.

This study was cross-sectional, and we did not clarify the relationship between the improvements in each factor and the height that could be crossed. Fall prevention in post-stroke patients with hemiplegia is very important. In the future, we would like to perform studies that address this topic further.

REFERENCES

1) Said CM, Goldie PA, Culham E, et al.: Control of lead and trail limbs during obstacle crossing following stroke. Phys Ther, 2005, 85: 413–427. [Medline]

2) Thurman DJ, Stevens JA, Rao JK, Quality Standards Subcommittee of the American Academy of Neurology: Practice parameter: assessing patients in a neurology practice for risk of falls (an evidence-based review): report of the Quality Standards Subcommittee of the American Academy of Neurology. Neurology, 2008, 70: 473–479. [Medline] [CrossRef]

3) Said CM, Galea MP, Lythgo N: People with stroke who fail an obstacle crossing task have a higher incidence of falls and utilize different gait patterns compared with people who pass the task. Phys Ther, 2013, 93: 334–344. [Medline] [CrossRef]

4) Tanaka H, Ibune M, Ishiwatari T, et al.: Obstacle crossing movement analysis in hemiplegic stroke patients, 2nd ed. Rigaku ryohogaku, 2005, 32 (Suppl 2): 533 (in Japanese).

5) Tanaka H, Ibune M, Ishiwatari T, et al.: An analysis of obstacle crossing movement in hemiplegic stroke patients: assessment of gait analysis tools. Rigaku ryohogaku, 2007, 34 (Suppl 2): 264 (in Japanese).

6) Tanaka H, Ibune M, Ishiwatari T, et al.: Obstacle crossing movements in hemiplegic stroke patients: an assessment of obstacle-foot distance. Journal of the 22nd Tokai Hokuriku Physical Therapy Symposium, 2006: 107 (in Japanese).

7) Tanaka H, Ibune M, Suwa K, et al.: Obstacle crossing movements in hemiplegic stroke patients, 3rd ed.: relationship between knee extension muscle force on unaffected side, load ratio on affected side, and gait speed. Journal of the 21st Tokai Hokuriku Physical Therapy Symposium, 2005: 182 (in Japanese).

8) Tanaka H, Ibune M, Kawakita S, et al.: Significant factors influencing the step-over action of hemiplegics. Rigakuryoho Kagaku, 2013, 28: 253–256 (in Japanese). [CrossRef]

9) Suzuki K, Nakamura R, Yamada Y, et al.: Relationship between maximum walking speed and standing balance in hemiparetic stroke patients. Jpn J Rehabil Med, 1992, 29: 577–580 (in Japanese). [CrossRef]

10) Abe H, Shibata H, Otsuka H, et al.: Effects of muscle training in the lower extremities on walking speed in completed stroke hemiplegic patients. Rigaku ryohogaku, 1991, 18: 529–533 (in Japanese).

11) Enishi K, Ohmine S, Kimura Y, et al.: The influencing factors of gait speed in hemiplegic patients—the relation between maximum gait speed and lower limb muscle strength. Rigaku ryohogaku, 1992, 19: 461–466 (in Japanese).

12) Karthikbabu S, Rao BK, Manikandan N, et al.: Role of trunk rehabilitation on trunk control, balance and gait in patients with chronic stroke: a pre-post design. Neurosci Med, 2011, 2: 61–67. [CrossRef]

13) Fujisawa H, Takeda R, Maeda S, et al.: Significance of functional reach test and one-footed standing duration in hemiplegia: relationship between balance and walking abilities. Rigaku ryohogaku, 2005, 32: 416–422 (in Japanese).

14) Miyakoshi H, Kido K, Kajikawa T, et al.: Training effect of unaffected lower extremity muscles in patients after cerebral vascular accident. Rigakuryoho Kagaku, 1997, 12: 69–71 (in Japanese). [CrossRef]

15) Öken O, Yavuzer G: Spatio-temporal and kinematic asymmetry ratio in subgroups of patients with stroke. Eur J Phys Rehabil Med, 2008, 44: 127–132. [Med-

line]

16) Shigeshima K, Handa T, Fujiwara T, et al.: Spatiotemporal parameters and asymmetry in hemiplegic gait: a comparison with healthy female subjects. Rigakuryoho Kagaku, 2012, 27: 205–211 (in Japanese). [CrossRef]

17) Verheyden G, Nieuwboer A, Mertin 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]

18) Patla AE, Prentice SD, Robinson C, et al.: Visual control of locomotion: strategies for changing direction and for going over obstacles. J Exp Psychol Hum Percept Perform, 1991, 17: 603–634. [Medline] [CrossRef]

19) Lee M, Shim J, Park M, et al.: A study of the stance limb during the crossing of obstacles of different heights by hemiplegic stroke patients. J Phys Ther Sci, 2010, 22: 317–321. [CrossRef]

20) Kasahara M, Yamasaki H, Aoki U, et al.: Relationship between one-leg standing time and knee extension strength in elderly patients. Jpn J Phys Fit Sports Med, 2001, 50: 369–373 (in Japanese). [CrossRef]

21) Murata S: Relationship between body sway of one-leg standing with vision and foot function in healthy female. Rigakuryoho Kagaku, 2004, 19: 245–249 (in Japanese). [CrossRef]

22) Miyazaki J, Murata S, Horie J, et al.: Relationship between 30-second one-leg standing time with eyes open and physical function of elderly men. Rigakuryoho Kagaku, 2010, 25: 379–383 (in Japanese). [CrossRef]

23) 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]

24) Balasubramanian CK, Bowden MG, Neptune RR, et al.: Relationship between step length asymmetry and walking performance in subjects with chronic hemiparesis. Arch Phys Med Rehabil, 2007, 88: 43–49. [Medline] [CrossRef]