

A Study of the Stance Limb during the Crossing of Obstacles of Different Heights by Hemiplegic Stroke Patients

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Abstract. [Purpose] This study was performed to investigate the balance of the stance limb of hemiplegic stroke patients during the crossing of obstacles of different heights. [Subjects] Twenty stroke patients (right hemiplegia) crossed obstacles of different heights (0 cm, 10 cm, 20 cm). [Methods] Stance time and muscle activity of the stance limb were measured during obstacle crossing. Two-way ANOVA was used to compare the stance time and muscle activities of the stance limb at the various obstacle heights. [Results] The results show that the stance time of the unaffected lower limb was significantly longer than that of the paretic lower limb and obstacle height increased, the stance time of the unaffected lower limb increased significantly. The participants exhibited increase in electromyography of the unaffected limb with increasing obstacle height. Particularly, the rectus femoris and gastrocnemius of the unaffected limb showed significant increases, and the tibialis anterior of the unaffected limb showed a significant difference between heights of 10 cm and 20 cm. Finally, the tibialis anterior and gastrocnemius showed significant difference between paretic and unaffected limb at all obstacle heights. [Conclusion] The results suggest that training the gastrocnemius of the paretic limb is an effective therapy for hemiplegic stroke patients.

Key words: Obstacle crossing, Stance limb, Hemiplegia

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INTRODUCTION

Gait is a complex procedure in which the human nervous system and the musculoskeletal system etc are generally used in continuous and repetitious movements during which one lower limb makes the body move forward while the other lower limb maintains stability¹⁾. In obstacle crossing, the postures are switched to relatively unstable postures in order to cross the obstacle and more harmonious control of the lower limbs and the trunk is required.

In particular, it can be said to be very important to maintain balance when the leading limb crosses an obstacle²⁾.

According to previous studies on obstacle crossing, the interjoint coordination that shows similar forms when crossing low obstacles will show larger differences as the obstacle height increases. In addition, given that as the obstacle height increases, the stability decreases on both feet during the stance phase, it can be seen that higher obstacles require more balance and control³⁾, and

especially require more muscle control in the stance limb²⁾. In obstacle crossing, crossing safely is the most crucial criterion and in this case, an index of safety can be said to be foot clearance⁴⁾ Austin et al. (1999) studied foot clearances of healthy adults in relation to obstacle height⁵⁾ and Lu et al. (2006) compared the foot clearances of young adults with those of elderly persons at different obstacle heights and showed that as obstacle height increased, the foot clearance of the leading limb increased more in elderly persons than in young adults³⁾.

The motor deficit occurring after strokes results in disorders in gaits which have an important impact on activities of daily living and obstacle crossing is one of the most frequent causes of falls⁶⁾. In the case of patients with hemiplegia, around a half of the causes of failure in obstacle crossing can be said to be the lack of the ability to maintain balance⁷⁾. Until now, most studies of obstacle crossing by patients with hemiplegia have focused on kinematic analyses of the leading limb and the trailing limb during the swing phase and few studies have studied the balance of the stance limb.

The purpose of this study was to identify the characteristics of obstacle crossing by patients with hemiplegia, who are at high risk of falling due to lack of balance because of hemiplegia, and their stability in relation to balance by measuring the stance time and muscle activities at different obstacle heights during the periods from the heel strike to toe-off of the paretic lower limb and the unaffected lower limb.

SUBJECTS AND METHODS

The subjects of this study were twenty male right hemiplegia patients. The description of the purpose and methods of this study was provided to them before the experiment and the experiment was conducted after getting their voluntary agreement. The subjects were selected from among patients who did not have any orthopedic disease, who could carry out gait without any gait aid, who could independently cross both 10 cm and 20 cm obstacles and scored at least 25 points in the Mini Mental Status Examination (MMSE), and thus could understand all the processes of the study. Their average age was 55.93 ± 0.3 years, height 168.34 ± 3.5 cm, weight 68.12 ± 2.1 kg and foot size 262.13 ± 1.4 mm.

All the subjects who participated in this study

stood at the end of a plate with a total length of 10 m and a width of 1 m including a 2 m long RS-scan system (RS scan Ltd., German) Plate produced for experiments and walked on the plate in their bare feet at natural speeds at the command, 'start', given by the experimenter. The obstacle used in the experiment was a 1.5 m long, 3 cm wide wooden beam which could be adjusted to 10 cm or 20 cm in the height. The obstacle was installed across the RS-scan system Plate in the middle of the 10 m Plate and the subjects crossed the obstacle randomly set at heights of 10 and 20 cm. Crossing the obstacles supporting the body with the paretic lower limb and crossing the obstacles supporting the body with the unaffected lower limb were performed three times, respectively, and the stance times from the heel strike to the toe-off of the stance limb and the muscle activity values of the stance limb of each condition were averaged and the average values were used as representative values in the analysis.

To analyze the stance time in obstacle crossing, data were collected at 126 frames/sec using Footscan 7 gait 2nd generation, which is a commercial program of the RS-scan System.

BioGraph Infiniti™ (Thought Technology Ltd., Canada) was used to measure the muscle activity of the trailing limb during the stance phase while the leading limb crossed the obstacle. Before making measurements, the electrode attachment sites were shaved and cleaned with alcohol cotton in order to reduce resistance, then three-pole surface electrodes (Triode™ electrode, Thought Technology Ltd., Canada) were attached to the rectus femoris, the hamstring, the tibialis anterior, and the gastrocnemius. Data collected at frequencies ranging from 20–500 Hz and 2,048 samplings per second were analyzed using the %RVC values for Root Mean Squares (RMS) provided by the BioGraph Infiniti™ (Thought Technology Ltd., Canada) software. For normalizing, at most frequently used value is the maximal voluntary isometric contraction (MVIC). However, this cannot be used for training for patients with neurological dysfunction and resting voluntary contraction (RVC) has been used by many researchers as the reference muscle contraction⁸⁾. In this study, we asked the subjects to stand comfortably and resting the muscle contraction in this posture for three seconds was used as the reference contraction to calculate the muscle activity of the stance limb, %RVC.

Table 1. Lengths of stance time at different obstacle heights in relation to the paretic limb (unit: msec)

Source	0 cm	10 cm	20 cm
Paretic limb	834.37 ± 90.47*	898.57 ± 24.14 [†]	1232.34 ± 153.81
Unaffected limb	1148.40 ± 46.32* [‡]	1475.42 ± 138.67 [†]	1469.90 ± 108.36 [‡]

*, [†], [‡] < 0.05.

NOTE. Each value represents the mean ± SE. Values with the same superscripts in the same row or column are significantly different (p<0.05) by the Scheffe test.

Table 2. Muscle activities of the stance limb at different obstacle heights in relation to the paretic limb (unit: %RVC)

Muscle	Source	0 cm	10 cm	20 cm
RF	Paretic limb	391.27 ± 42.34	365.20 ± 42.48	468.67 ± 80.31
	Unaffected limb	310.14 ± 41.74*	411.28 ± 62.88 [†]	470.83 ± 71.77* [†]
H	Paretic limb	652.28 ± 168.31	663.23 ± 95.40	808.00 ± 125.81
	Unaffected limb	581.44 ± 134.83	616.02 ± 133.69	767.95 ± 185.72
TA	Paretic limb	1823.86 ± 310.19*	1610.23 ± 269.18 [†]	2177.97 ± 435.35 [‡]
	Unaffected limb	434.14 ± 77.82*	499.93 ± 126.37 ^{†a}	684.12 ± 182.82 ^{‡a}
GCM	Paretic limb	575.15 ± 73.85*	657.12 ± 79.77 [†]	715.52 ± 67.60 [‡]
	Unaffected limb	865.56 ± 115.93* ^a	1167.03 ± 166.36 ^{†b}	1160.60 ± 180.43 ^{‡ab}

*, [†], [‡], ^a, ^b < 0.05, RF: rectus femoris, H: hamstring, TA: tibialis anterior, GCM: gastrocnemius.

NOTE. Each value represents the mean ± SE. Values with the same superscripts in the same column or row are significantly different (p<0.05) by the Scheffe test.

The data obtained from three measurements under each condition were averaged and the average values were used as representative values. Two-way ANOVA was used to compare and analyze each measured value and Scheffe's post hoc test was used for the comparison of heights. The significance level α to test statistical significances was chosen as 0.05 and the commercial statistical program SPSS 12.0 was used for statistical processing of the data.

RESULTS

The stance times at different obstacle heights and in relation to the paretic limb were compared. Statistically significant differences were found in relation to paresis (p<0.05) (Table 1). In addition, although the stance time did not show statistically significant differences at different obstacle heights, based on the results of the post hoc tests, in the case of obstacle crossing supporting the body with the unaffected limb, the stance time was significantly longer when crossing the 20 cm obstacle than when walking on the level with no obstacle (p<0.05).

There was no interaction between obstacle heights and paresis (p>0.05).

The muscle activities of the stance limb at different obstacle heights and in relation to the paresis were compared and there was a tendency of increasing muscle activities as obstacle heights increased in both the paretic lower limb and the unaffected lower limb. However, there were significant differences between the paretic lower limb and the unaffected lower limb only in the tibialis anterior and the gastrocnemius (p<0.05) (Table 2).

In the case of the rectus femoris, based on the results of the post hoc tests, it could be seen that muscle activities significantly increased as obstacle heights increased in the unaffected lower limb (p<0.05).

In the case of the hamstring, although muscle activities increased as obstacle heights increased, no significant differences were found (p>0.05), and, although the muscle activity of the paretic lower limb was higher than that of unaffected lower limb at all the heights, again, there were no statistically significant differences (p>0.05).

In the case of the tibialis anterior, the muscle activity of the paretic lower limb was significantly higher than that of unaffected lower limb at all the obstacle heights ($p < 0.05$). In the case of the unaffected lower limb, the muscle activity the significantly increased at the 20 cm obstacle height above that of the 10 cm obstacle height ($p < 0.05$).

Finally, in the case of the gastrocnemius, the muscle activity of the unaffected lower limb was significantly higher than that of the paretic lower limb at all the obstacle heights ($p < 0.05$), and, it could be seen that, as the obstacle heights increased, the muscle activity of the gastrocnemius of the unaffected lower limb, significantly increased ($p < 0.05$).

DISCUSSION

In obstacle crossing, patients with hemiplegia use various types of strategies in order not to lose balance in obstacle crossing. Decreased muscle strength, muscle power, balance disturbance etc. influence these strategies center of mass movement speeds decrease in obstacle crossing compared to healthy adults⁹.

Said et al. (2005) studied balance in obstacle crossing with 12 patients with hemiplegia and 12 healthy adults as subjects. They reported that patients with hemiplegia were more unstable compared to healthy adults and that, to compensate for this instability, patients with hemiplegia reduced the anterior-posterior movement speed of the center of mass and moved the center of mass further posterior when the paretic lower limb was crossing the obstacle¹⁰. In a subsequent study, they reported that the reason why the movement speed of the center of mass of patients with hemiplegia decreased in obstacle crossing was because of the paretic lower limb toe-off of the paretic lower limb did not occur efficiently to decrease and because of this, the toe clearance showed tendency to decrease¹¹. They also reported that stability could be secured by reducing the walking speed and this could reduce instances of the leading limb being caught by the obstacle and resulting in forward falls. In the present study, also, the stance time became longer as obstacle heights increased and this can be considered as strategy to secure stability. In addition, the time to cross the obstacle with the affected lower limb while supporting the body with the paretic lower limb was longer than the time to

cross the obstacle with the unaffected lower limb while supporting the body with the paretic lower limb. Accordingly it can be said that the crossing speed was reduced because toe-off of the paretic lower limb did not occur efficiently immediately before the obstacle crossing as reported in previous studies.

The muscle activities of the stance limb at different obstacle heights and in relation to paresis were analyzed and based on the results, large differences were shown in relation to paresis the quadriceps and the lower leg muscles, and the muscle activity of the unaffected lower limb generally increased as obstacle heights increased. Perry (1992) reported that the action of the quadriceps was important for the weight of support and the stability of the knee joint during midstance and the results of the present study, indicating that the muscle activity of the quadriceps of the unaffected lower limb increased as obstacle heights increased, can be interpreted as a strategy to secure stability, consistent with the results of previous studies¹.

In addition, remarkable differences were shown at the tibialis anterior and the gastrocnemius between the paretic lower limb and the unaffected lower limb and in the case of the gastrocnemius, lower muscle activities were shown in the affected lower limb compared to the unaffected lower limb. These results explain the longer stance time when supporting the body with the unaffected lower limb and crossing the obstacle with the paretic lower limb. In other words, the weak muscle activity of the gastrocnemius of the paretic lower limb results in a weak toe-off immediately before the swing phase and this induces inefficient motions when the paretic lower limb crosses an obstacle, lengthening the stance time of the unaffected lower limb.

Lu et al. (2008) argued that an increase of ankle stability would affect the stability of knee-ankle coordination and this would help obstacle crossing. We consider that in the present study, the muscle activity of the tibialis anterior increased remarkably in order to compensate for the weak gastrocnemius and maintain ankle stability¹².

Taking these results together, it can be said that, the abnormal form of obstacle crossing by patients with hemiplegia is not only a problem of the paretic lower limb but also the combination of both lower limbs. If stability during the stance phase is increased and toe-off is promoted through intensive

reeducation of the gastrocnemius of the paretic lower limb hemiplegic patients' obstacle crossing would become more like that of healthy adults' obstacle crossing and this would help them cross obstacles more safely.

Given these results, training the gastrocnemius of the paretic lower limb with efficient toe-off can be an effective therapy for hemiplegic stroke patients. And also training the gastrocnemius of the paretic lower limb can be to shorten the stance phase of unaffected lower limb. Therefore the strategy of both limbs become similar. We think that more studies will be necessary with diverse approaches to balance in obstacle crossing by patients with hemiplegia.

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