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ORIGINAL ARTICLE

RELATIONSHIP OF OBSERVED GAIT DEVIATIONS WITH PHYSICAL FUNCTIONS AND WALKING ABILITY IN STROKE PATIENTS.

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Abstract We conducted an observational gait assessment and examined the relationship of gait deviations with physical function and walking ability. A total of 57 stroke patients admitted to a rehabilitation unit, who could walk unaided or under close supervision, were enrolled in the study (37 men; 20 women; 62.2 ± 11.2 years of age; elapsed time since the onset of stroke: 90.9 ± 39.9 days). We combined and partially modified several assessment forms used for gait evaluation. With regard to physical functions, we assessed: lower limb paralysis, sensory impairment, lower limb spasticity, range of motion, lower limb muscle strength, lower limb weight-bearing, and standing balance. We conducted a 10-meter walk test to assess patients' walking ability. In order to identify variables that affect the total gait assessment score, a multiple regression analysis was performed. The following parameters were statistically associated with gait deviations: number of steps required to walk 10 meters (standard partial regression coefficient=0.68), affected side hip abductor strength (–0.23), ankle plantar flexor spasticity (0.18), and maximum weight-bearing rate on the unaffected side (0.16). We established the relationship of gait deviations with physical function and walking ability.

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Key words: stroke; gait observation; gait deviation.

Introduction

Improving walking ability helps patients regain independence after a stroke[1]. Physiotherapy studies evaluate gait disturbances in stroke patients as well as the treatment for this condition. In the clinical setting, physiotherapists assess patients' walking ability by conducting 10-meter and 6-meter walking tests in conjunction with a close observation of patients' gait[2]. Particularly, observation-based clinical gait assessment is widely conducted because it is convenient, it does not require special equipment, or long-distance walks[3]. Gait consists of spatio-temporal, kinetic, and kinematic deviations[4]. Gait is analyzed by assessing deviations in numerous gait parameters. Gait deviation implies a deviation in a gait parameter, which implies a deviation from normal gait. Many gait deviations imply a large deviation in a gait parameter or the presence of deviations in multiple gait parameters. Some studies involving stroke patients established a relationship between walking speed and the following parameters related to gait deviations: the percentage of stance phase on the unaffected side, hip extension angle during terminal stance, stride length of the affected side, prolongation of the pre-swing phase, knee joint angle during mid-stance, ankle joint angle during mid-swing, and thigh and knee joint angle between the initial swing and mid-swing[5-8]. However, these studies did not elucidate whether walking speed would decrease if there were deviations in multiple parameters or a large deviation. Furthermore, the relationship between gait deviations and physical functions has not been elucidated. "Physical function" is defined as the physical condition that affect motor function such as degree of paralysis,

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balance, muscle strength, range of joint motion, etc. Therefore, in this study, we conducted an observational gait assessment to elucidate the relationship between gait deviations and factors such as physical function and walking ability.

Method

1. Subjects

Subjects were selected among stroke patients according to the following criteria: stroke patients admitted to the rehabilitation unit (wihin 2 month from the onset of stroke after receiving treatment for acute stroke); patients who received a score below 1 on the modified Ranking Scale before stroke onset; patients capable of walking at least 20 meters unaided or under close observation; patients without disease affecting gait except for stroke; and patients who agreed to participate upon understanding the objective of the study. A total of 57 patients (37 men; 20 women) with a mean ± SD age of 62.2 ± 11.2 years and time from stroke onset of 90.9 ± 39.9 days were enrolled in the study. There were 28 patients with cerebral hemorrhage and 29 patients with cerebral infarction.

All the subjects provided written informed consent following the explanation of the significance, objectives, and methods of the study. The present study was conducted in accordance with the Declaration of Helsinki and was approved by The Committee of Medical Ethics of Hirosaki University Graduate School of Medicine (Approval Number: 2013-175).

2. Measurements

All measurements and assessment of all the parameters except range of motion (ROM) were performed by one investigator (the lead author). We measured and assessed the following parameters:

2.1 Lower limb paralysis severity

Lower-extremity motor recovery was assessed with the Brunnstrom recovery stages (Br.S)[9].

2.2 Lower limb sensation

To assess superficial sensation, tactile sensitivity was examined in the soles of the feet. The assessment procedure consisted of randomly stimulation to the left or right sole of the foot with cotton wool. Subjects were asked to close their eyes and tell the examiner which sole the stimulus was applied to. The stimulus was applied to each sole 4 times, and those who could not answer correctly even once were diagnosed with sensory impairment.

Joint proprioception was assessed in the hips, knees, ankles, and hallux. The subjects were placed in a supine position while the subjects' lower extremities of the affected side were passively moved by the examiner. In response to this, the subjects were asked to move the lower extremity of the unaffected side in the same manner as that of the affected side. This would be repeated 4 times, and if a subject could not respond correctly even once, they were diagnosed with sensory impairment.

2.3 Lower limb spasticity

The Modified Modified Ashworth Scale (MMAS)[10] was used to assess spasticity (Table 1). The flexor, extensor, and adductor muscle of the hip; the flexor and extensor muscles of the knee; and the ankle plantar flexor was examined. The hip adductor muscles and ankle plantar flexors were assessed by placing the subjects in a supine position, whereas the flexor and extensor muscles of the hips and knees were assessed by placing the subjects in a lateral position. The MMAS scores were determined by moving each joint through its full ROM for 1 second.

Table 1. Modified Modified Ashworth Scale

0	No increase in muscle tone
1	Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the range of motion when the affected parts are moved in flexion or extension
2	Marked increase in muscle tone, manifested by a catch in the middle range and resistance throughout the remainder of the range of motion, but affected parts easily moved
3	Considerable increase in muscle tone, passive movement difficult
4	Affected parts rigid in flexion or extension

2.4 Range of motion

The following 7 joint ROMs were assessed in both sides: hip abduction, hip adduction, internal rotation and extension, knee extension, and ankle dorsiflexion with the knee flexion and the knee extension. The measurements were performed according to the "Method Guidelines for Range of Motion Measurement"[11] of the Japanese Association of Rehabilitation Medicine and the Japanese Orthopaedic Association. Measurements were performed by the lead author and another physiotherapist; while one was moving or holding the torso or lower extremities, the other measured ROM in 5° increments using a goniometer designed at Tokyo University. We repeated the measurements until we were able to ensure intra-rater reliability in advance, and then we calculated the mean. We used the Spearman-Brown formula to calculate the number of measurements necessary to achieve an intraclass correlation coefficient ≥ 0.81.

2.5 Lower limb muscle strength

According to the manual muscle test (MMT) grading system[12], muscle strength of the followings were assessed in the affected side: hip flexor, extensor and abductor, knee extensor, and ankle plantar flexor. An MMT grade below 3 was defined as an indication of muscle weakness.

2.6 Maximum weight-bearing rate (WBR)

The subjects' paretic and non-paretic legs were placed on 2 separate scales (Tanita analog health meter RAINBOW THA-528-SW. TANITA Co., LTD, Tokyo, Japan) in a standing position with their heels 10cm apart, and the foot angle was set at 45°. Then, the one leg was loaded with a maximum weight and maintained in that position for 5 seconds. The process of weighing was documented with a digital still camera (trade name: EXFH100. CASIO COMPUTER CO., LTD, Tokyo, Japan). The right and left legs were loaded with a maximum weight for 3 times each. The footage was transferred to a personal computer and viewed using Windows media player (Microsoft Corporation, Redmond. USA). We calculated the mean of maximum and minimum values shown on the scale at maximum weight load. Maximum weight-bearing on the paretic and non-paretic legs were determined by calculating the mean of the 3 measurements for each leg. The maximum WBR of the affected and unaffected legs were calculated by dividing each leg's maximum weight-bearing capacity by the body weight. Thus, the maximum WBR of the affected and unaffected legs were calculated.

2.7 Balance

We employed the Berg balance scale (BBS)[13] and recorded the total scores. The BBS is 14-item scale to evaluate static and dynamic balance. The items are scored from 0 to 4, and total score range is between 0 as worst and 56 as best. The subjects who were wearing orthotic devices were allowed to keep them on during the BBS test.

2.8 10-meter walk test (10MWT)

The subjects were instructed to walk 10

meters along a 16-meter walkway, and the walking time and the number of steps were measured in 3 trials. During the assessment, the subjects were asked to walk as fast as possible. The values obtained from a trial showing the shortest walking time were recorded as the number of steps and walking time for the 10MWT[14].

2.9 Gait deviation assessment

Gait assessment

Observational gait assessments are conducted frequently. However, there are concerns regarding the accuracy and the reproducibility of their results. To improve the accuracy and reliability of observational gait assessments, several gait assessment forms have been designed specifically for stroke patients. In some studies, assessment forms, which were not specifically designed for stroke patients, were used to assess gait in stroke patients[2, 15-19]. However, neither of them is used as a standard gait assessment tool[20]. Therefore, using multiple existing assessment forms as a reference, we identified parameters that were useful for assessing gait deviations in stroke patients, designed assessment forms consisting of these parameters, and used them for gait assessment [21].

Specifically, to create Table 2, we combined and partially modified the Tinnetti gait assessment[15, 22], Wisconsin gait scale[17, 23], and Rivermead visual gait assessment[18, 23] used for stroke patients. Gait assessment forms were comprised of 25 parameters, and each parameter was rated on a 3-point scale. The total score range is between 25 as normal and 72 as worst. A higher score implies more deviation from the normal gait. The following items were observed: knee (normal or flexion/extension)/ heel strike during initial contact; knee during the period between loading response and mid-stance; trunk (normal or flexion/extension)/pelvis lateral displacement/knee (normal or flexion/extension) during mid-stance; hip extension/ankle planter flexion/guardedness during terminal stance; stance time on the affected side; weight-shift to the affected side; knee flexion during the period between initial swing and mid-swing; external rotation of leg during initial swing; trunk (front and rear view/lateral view)/pelvic elevation/circumduction/ankle/weight-shift to the affected side during the period between mid-swing and terminal swing; weight-shift to the unaffected side; pelvis during terminal swing; step length of the affected/unaffected side/foot clearance of the affected side; use of a cane; and step width. We confirmed intra-rater reliability in advance using Kendall's coefficient of concordance, and it ranged between 0.68 and 0.88[21].

Gait assessment rating

The subjects were asked to walk a round-trip along a 10-meter walkway at a comfortable speed. The video camera recorded the subject during a 5-meter walk within the 10-meter walkway. The video camera was mounted on a tripod, and the tripod was mounted at a height corresponding to each subject's greater trochanteric height. One camera was placed at a lateral point from the center of the 10-meter walkway at a 4.5-meter away. Another camera was mounted 1-meter away from the end of the walkway. The subjects were filmed simultaneously by two cameras placed in two different spots as they walked a round trip along the walkway (Fig. 1). During the walking test, the subjects were allowed to use walking aids and orthoses, which they usually use in their daily life or during physiotherapies. Considering the risk of falling, one physiotherapist accompanied the subjects along the walkway during filming. The camera footage was transferred to a notebook computer (LS550/C; 15-inch display; OS: Windows 7. NEC Corporation, Tokyo, Japan). The video footage was split into 2 files: one showing the front

Table 2. Gait assessment

	Initial contact affected side	
1	**Initial contact affected side, knee (flexion/extension)**	
	1. Normal	Neutral position (0°~5°)
	2. Flexion/hyperextension	Flexion/hyperextension
2	**Initial contact affected side, heel strike**	
	1. Heel strike	Heel makes initial contact with the floor.
	2. Foot flat	Foot lands with weight distributed over entire foot.
	3. No contact of heel	Foot lands on lateral border of the foot or toes.
	Loading response affected side	
3	**Loading response to mid stance of affected side, knee (flexion/extension)**	
	1. Normal	Knee extends from a 15° flex position to neutral position.
	2. Rapid extension	Knee extends rapidly from the flex position.
	3. Remaining in flexion/extension	Knee remains in flexion or extension.
	Mid stance affected side	
4	**Mid stance of affected leg, trunk (flexion/extension)**	
	1. Normal	Maintain erect posture
	2. Flexion/extension	Trunk flexion/extension, when the great trochanter crosses the lateral malleolus, the acromion deviates forward or backward.
	3. Marked flexion/extension	Flexion: When the great trochanter crosses the lateral malleolus, the acromion in front of the toe. Extension: When the great trochanter crosses the lateral malleolus, the acromion is behind the heel.
5	**Mid stance of affected leg, pelvis lateral displacement**	
	1. Normal	No displacement during the stance phase.
	2. Pelvic lateral displacement	Clear lateral displacement of the pelvis during mid stance.
6	**Mid stance of affected leg, knee (flexion/extension)**	
	1. Normal	Neutral position (0°~5°)
	2. Flexion/hyperextension	flexion/hyperextension
	Terminal stance to Pre swing affected side	
7	**Terminal stance to Pre swing affected leg, hip extension**	
	1. Equal to unaffected leg	Hips equally extend during push-off. Maintains erect posture during Terminal stance to Pre swing.
	2. Reduced hip extension	Hip extends at least to neutral, but less than unaffected side.
	3. Marked reduced hip extension	Forward trunk and hip flexion at toe-off.
8	**Terminal stance to Pre swing affected leg, plantar flexion decreased**	
	1. Equal to unaffected leg	Plantar equally flexed during toe-off.
	2. Decreased plantar flexion	Plantar flexion decreased compared with the unaffected leg.
	3. Marked decreased	No toe-off or heel is passively away from the floor with unaffected foot landing.
9	**Terminal stance and pre swing affected leg, guardedness (pause prior to advancing affected leg)**	
	1. None	Good forward momentum with no hesitancy noted.
	2. Slight	Slight pause prior to toe-off.
	3. Marked hesitation	Subject pauses prior to toe-off.
	Affected side stance phase	
10	**Stance time on affected side**	
	1. Equal to unaffected leg	An equal amount of time is spent on the affected leg compared to the unaffected leg during single leg stance.
	2. Unequal to unaffected leg	The subject remains on the affected leg for a shorter period of time compared to the unaffected leg during single leg stance.
	3. Very brief	The subject spends the least amount of time to accomplish advancing the unaffected leg.
11	**Weight shift to the affected side (with or without a gait aid)**	
	1. Full shift	Head and trunk shift laterally over the affected inside foot during single stance.
	2. Decreased shift	Head and trunk crosses midline, but not over the affected foot.
	3. Very limited shift	Head and trunk does not cross midline, minimal weight shift in the direction of the affected side.

Initial swing affected side	
12 **Knee flexion from initial swing to mid swing**	
1. Normal	Affected knee flexes equally to unaffected side.
2. Reduced knee flexion	Affected knee flexes, but less than the unaffected knee.
3. None	Knee remains in extension throughout swing.
13 **External rotation during initial swing (observe direction of toe)**	
1. Same as unaffected leg	External rotation is the same as that in the unaffected leg.
2. Increased rotation	External rotation <45°, but more than the uninvolved side.
3.Marked increased rotation	External rotation >45°.
Mid swing of affected leg, to terminal swing	
14 **Mid swing of affected leg, trunk (flexion/extension)**	
1. Normal	Maintain erect posture
2. Flexion/extension	Trunk flexion/extension, when both ankles cross at the sagittal plane, the acromion deviates forward or backward.
3. Marked flexion/extension	Flexion: the acromion is in front of the unaffected toe during mid swing of the affected leg. Extension: the acromion is behind the unaffected heel during mid swing of the affected leg.
15 **Mid swing of affected leg, lateral tilt of trunk (unaffected/affected)**	
1. Normal	Maintains erect posture during swing phase.
2. Lateral tilt of trunk	Trunk tilts laterally during mid swing, head is over the vertical line of the foot.
3. Marked lateral tilt of trunk	Trunk tilts laterally during mid swing, head crosses over the vertical line of the foot.
16 **Hip hiking at mid swing**	
1. None	Pelvis slightly dips during swing.
2. Elevation	Pelvis is elevated during swing phase.
3. Marked elevation	Little true hip flexion, subject contracts lateral trunk muscles and elevates hip during swing.
17 **Circumduction at mid swing (observe path of affected heel)**	
1. None	Affected foot adducts no more than the unaffected foot during swing.
2. Moderate circumduction	Affected foot adducts up to one shoe width during swing.
3. Marked circumduction	Affected foot circumducts more than one shoe width during swing.
18 **Mid swing of affected leg, ankle in excess plantar flexion**	
1. Normal	Ankle in neutral position or dorsiflexion during swing.
2. Plantar flexion	Ankle in plantar flexion during swing.
3. Marked plantar flexion	Ankle in excess plantar flexion, sometimes stumble by toe.
19 **Weight shift to the unaffected side (with or without a gait aid)**	
1. Full shift	Head and trunk shift laterally over the unaffected inside foot during single stance.
2. Decreased shift	Head and trunk cross the midline, but not over the unaffected foot.
3. Very limited shift	Head and trunk do not cross the midline, minimal weight shift in the direction of the unaffected side.
Terminal swing affected leg	
20 **Terminal swing affected leg, pelvic rotation (observe ASIS of affected side)**	
1. Forward	The pelvis is rotated forward to prepare for heel strike.
2. Neutral	Posture is erect with pelvis in neutral rotation.
3. Retracted	Pelvis has marked lag behind the unaffected pelvis.
Step length and toe clearance	
21 **Step length of unaffected side (observe when passing through center of the screen)**	
1. Normal	The heel of the unaffected foot clearly advances beyond the toe of the affected foot.
2. Reduced step length	The heel of the unaffected foot does not advance beyond the toe of the affected foot.
3. Marked reduced step length	The unaffected foot is placed behind or up to, but not beyond the affected foot.
22 **Step length of affected side (observe when passing through center of the screen)**	

1. Normal	The heel of the affected foot clearly advances beyond the toe of the unaffected foot.
2. Reduced Step length	The heel of the affected foot does not advance beyond the toe of the unaffected foot.
3. Marked reduced step length	The affected foot is placed behind or up to, but not beyond the unaffected foot.
23 **Toe clearance of affected side**	
1. Normal	Toe clears the floor throughout the swing.
2. Slight drag	Toe drags slightly at beginning of the swing phase.
3. Marked drag	Toe drags during the majority of the swing.
Other items	
24 **Use of a hand held gait aid**	
1. No gait aid	
2. Minimal gait aid use	Gait aid used minimally, may rock the legs of a quad cane as weight is transferred forward.
3. Marked use	Transfers weight through the aid.
25 **Stance width (measure distance between feet prior to toe-off of the affected foot)**	
1. Normal	Up to one shoe width between feet.
2. Moderate	Up to two shoe widths between feet.
3. Wide	Greater than two shoe widths between feet.

ASIS, Anterior superior iliac spine

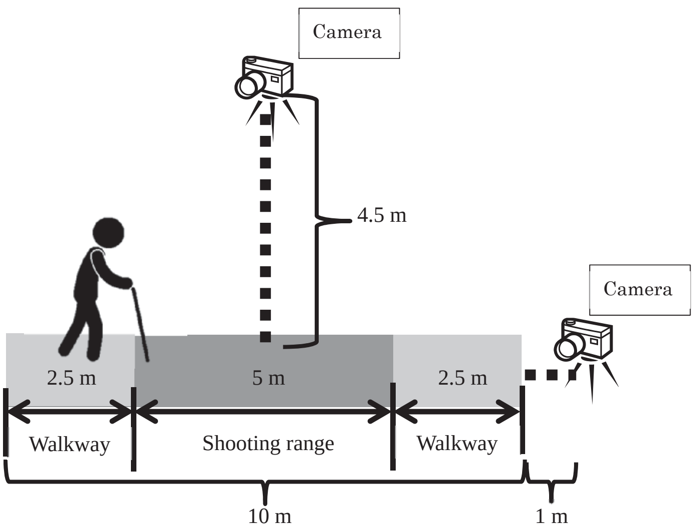

Fig. 1 Setting of walkway and digital cameras for measurement

and rear view of the subjects as they walked along the walkway, and the other presenting the paretic and non-paretic sides of the subjects as they walked. The video files were viewed in full-screen using Windows Media player. Upon viewing the footage, the examiner calculated the total gait assessment score.

2.10 Other variables

We obtained the following information from the subjects' medical records: age, time elapsed since the onset, type of stroke (cerebral infarction or cerebral hemorrhage), Functional Independence Measure (FIM); and the Mini-Mental State Examination (MMSE).

3. Statistics

To elucidate the association of gait deviations with physical function and walking ability, we set the total gait assessment score as the dependent variable, whereas the following parameters were set as the independent variables: sex, age, time elapsed since the onset of stroke, affected side, type of stroke, total BBS score, walking time recorded during the 10MWT, the number of steps recorded during the 10MWT, Br.S, MMAS (flexor, extensor, and adductor muscles of the hip; flexor and extensor muscles of the knee; and ankle plantar flexor), superficial sensation (planta), proprioception (hip, knee, ankle, and toe); hip abductor strength, hip flexor strength, knee extensor strength, ankle plantar flexor strength, unaffected side WBR, affected aside WBR, and ROM (hip abduction, hip adduction, internal hip rotation, knee extension, and ankle dorsiflexion with the knee flexed and extended). Eight patients could not be placed in a prone position for the assessment of hip extensor strength and ROM. Therefore, these 2 parameters were excluded from the analysis. We conducted a multiple regression analysis with significance level set at 0.05. For statistical analysis, we used SPSS12.0J (SPSS Japan, Tokyo, Japan).

Results

1. Measurement outcome (Table 3)

The subjects' stage of recovery according to the Br.S was rated as follows: stage III, 17 subjects; stage IV, 10 subjects; stage V, 14 subjects; and stage VI, 16 subjects. Regarding the subjects who were diagnosed with sensory impairment in the lower extremity, 19 subjects had impaired superficial sensation (planta); 11 subjects, impaired proprioception in the hip or knee; 10 subjects, sensory impairment in the ankle; and 23 subjects, sensory impairment in the toes. Regarding the subjects with lower limb spasticity, 25 patients had hip flexor spasticity (MMAS1, 17 subjects; MMAS2, 8 subjects); 14 patients, hip extensor spasticity (MMAS1, 12 subjects; MMAS2, 2 subjects); 22 patients, hip adductor spasticity (MMAS1, 11 subjects; MMAS2, 11 subjects); 6 subjects, knee flexor spasticity (MMAS1, 3 subjects; MMAS2, 3 subjects); 4 subjects, knee extensor spasticity (MMAS2, 4 subjects); and 29 subjects, ankle plantar flexor spasticity (MMAS1, 6 subjects; MMAS2, 22 subjects; MMAS3, 1 subject). Regarding the subjects with reduced muscle strength in the affected leg, 30 subjects had reduced hip extensor strength; 34 subjects, reduced hip abductor strength; 9 subjects, reduced hip flexor strength; 22 subjects, reduced knee extensor strength; and 50 subjects, reduced ankle plantar flexor strength. The ROM in the unaffected and affected side were as follows: hip abduction, 31.1 ± 5.9° and 29.5 ± 5.6°; hip adduction, 9.3 ± 2.9° and 9.6 ± 2.7°; internal hip rotation, 18.3 ± 11.1° and 18.5 ± 8.5°; hip extension, 19.8 ± 7.2° and 18.3 ± 6.5°; knee extension , 0.4 ± 2.7° and 0.6 ± 3.8°; ankle dorsiflexion with the knee flextion, 26.1 ± 8.0° and 21.5 ± 7.3°; ankle dorsiflexion with the knee extension, 11.5 ± 7.4° and 7.5 ± 5.7°.The maximum WBR on the unaffected side and affected side was 0.85 ± 0.06 and 0.72 ± 0.16, respectively. The total BBS score was 48.6 ± 6.5. The time recorded during the 10MWT was 15.9 ± 10.4 seconds, and the number of steps was 23.7 ± 7.8. The total gait assessment score was 38.2 ± 8.1. The total FIM score was 105.3 ± 15.0. The MMSE score was 26.2 ± 4.4.

2. Variables that affect gait deviation

The results of the stepwise multiple regression analysis are shown in Table 4. The following were selected as the variables that affect the total gait assessment score: time recorded during the 10MWT, hip abductor strength, MMAS (ankle plantar flexor spasticity), and maximum WBR on the unaffected side. The regression equation had high accuracy of prediction (R^2 = 0.80). The relationships between total gait assessment score and the time recorded during

Table 3. Outcome measures for subjects with stroke

Brunnstrom stages (n)	Ⅲ / Ⅳ / Ⅴ / Ⅵ		17 / 10 / 14 / 16		
Superficial sensation (n)	Planta			19	
Proprioceptive sensation (n)	Hip・Knee/Ankle/toe			11/10/23	
Modified Modified Ashworth Scale (n)			1	2	3
	Hip	Flexor	17	8	0
		Extensor	12	2	0
		Adductor	11	11	0
	Knee	Flexor	3	3	0
		Extensor	0	4	0
	Ankle	Plantar Flexor	6	22	1
Muscle weakness (n)	Hip	Extensor		30	
		Abductor		34	
		Flexor		9	
	Knee	Extensor		22	
	Ankle	Plantar Flexor		50	
Range of motion (degrees)			Unaffected / Affected		
	Hip	Abduction	31.1 ± 5.9 / 29.5 ± 5.6		
		Adduction	9.3 ± 2.9 / 9.6 ± 2.7		
		Internal rotation	18.3 ± 11.1 / 18.5 ± 8.5		
		Extension	19.8 ± 7.2 / 18.3 ± 6.5		
	Knee	Extension	0.4 ± 2.7 / 0.6 ± 3.8		
	Ankle	Dorsiflexion (with knee Flexion)	26.1 ± 8.0 / 21.5 ± 7.3		
		Dorsiflexion (with knee extension)	11.5 ± 7.4 / 7.5 ± 5.7		
Maximum weight-bearing rate			Unaffected / Affected		
			0.85 ± 0.06 / 0.72 ± 0.16		
Berg balance scale score				48.6 ± 6.5	
10-meter walk test	Time (seconds)			15.9 ± 10.4	
	Number of steps			23.7 ± 7.8	
Gait assessment score				38.2 ± 8.1	
Functional Independence Measure score				105.3 ± 15.0	
Mini-Mental State Examination score				26.2 ± 4.4	

the 10MWT, hip abductor strength, MMAS (ankle plantar flexor spasticity), and maximum WBR on the unaffected side are shown in the scatter diagram (Fig. 2).

Discussion

1. The relationship between the variables that affect gait deviation

Our findings showed that the following variables were associated with gait deviations: walking time during the 10MWT, hip abductor strength, ankle plantar flexor spasticity, and weight loaded on the unaffected side. Gait deviations in stroke patients are characterized by functional impairments and compensatory adaptation[4]. Some studies reported that deviations in joint movements may remain despite improvements in walking ability from 3 weeks to 48 weeks after a stroke[24]. Gait comparison between stroke patients and healthy individuals at a matched walking speed revealed differences in single-limb support time and joint movements between pre-swing and swing phases[25]. Similarly, in this study, we found that gait deviations were associated with the time recorded during the 10MWT, hip abductor strength of the affected leg, ankle plantar flexor spasticity, and maximum WBR on the unaffected side (Fig. 2). The time recorded during the 10MWT had the strongest association with the total gait assessment score. That is, the more deviations there are in gait, the slower the walking speed is. In stroke patients, walking

Table 4. Result of multiple regression analysis between gait assessment score and other outcome measures

	B	Standard error	β	p
Constant	11.35	7.91		0.16
Time recorded during the 10-meter walk test	0.53	0.06	0.68	0
Muscle strength of hip abductor	−3.8	1.31	−0.23	0.01
Modified Modified Ashworth Scale (ankle plantar flexor)	1.53	0.61	0.18	0.02
Maximum weight-bearing rate (unaffected side)	21.74	9.47	0.16	0.03

Analysis of variance: $p < 0.01$; $R^2 = 0.80$; Adjusted $R^2 = 0.78$; Durbin-Watson ratio=2.067

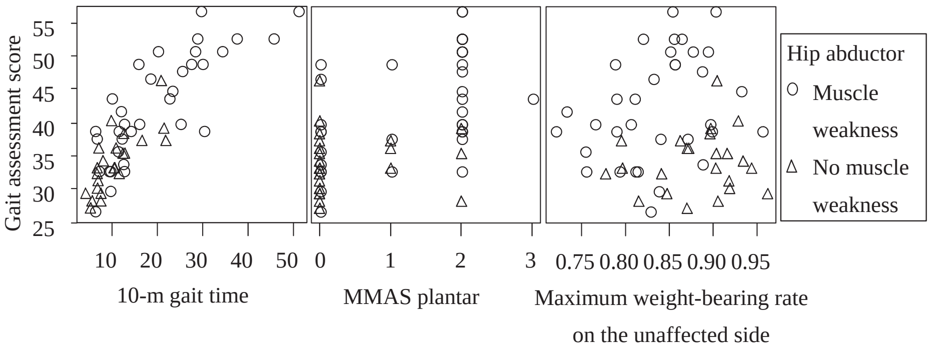

Fig. 2 The scatter plot of gait assessment score and each variable
MMAS, Modified Modified Ashworth Scale

speed is not determined by the extent of lower limb paralysis; it is determined by lower limb strength[17] and balance[26], and it is one of the indices of the degree of walking independence [1, 27]. We believe that the assessment forms employed in this study captured gait associated with walking speed.

Furthermore, hip abductor strength on the affected side is affected by the ability to perform voluntary movements of the lower extremities. All of the Br.S III subjects in this study had an MMT grade of the hip abductor strength below 3 and trended upwards in terms of the total gait assessment score in comparison with the subjects with other Br.S stages (Fig. 3). Therefore, since hip abductor strength affected gait, it can be concluded that the ability to perform voluntary movements of the lower extremities also affected gait. Limb strength of the affected side was found to be associated with walking speed, cadence, and functional independence in stroke patients[26]. Particularly, hip flexor[7], knee extensor[14] and ankle plantar flexor[7] muscles were found to affect walking speed. By contrast, hip abductor muscles are involved in frontal-plane weight-

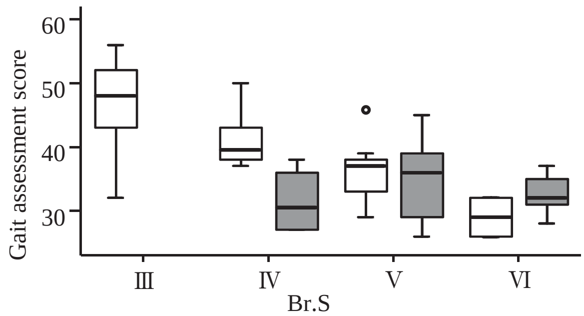

Fig. 3 Gait assessment score according to the presence or absence of hip abductor muscle strength for each Br.S (Box plot).
□ : Hip abductor muscle weakness; ■ : No muscle weakness
Br.S, Brunnstrom recovery stages

shifts[28], and in addition to being more associated with cadence[29] in comparison with other muscles, they were reported to be involved in double support time and temporal left-right asymmetries similarly to ankle plantar flexors[30]. Besides other variables that were selected, hip extensor strength with an MMT grade ≥ 3 can be a useful index for assessing the relationship between gait and the time recorded during the 10MWT.

Ankle plantar flexor spasticity is associated with reduced stride length and cadence[31, 32], left-right asymmetry in step length, and single leg stance time[7], and it affects deviations in joint movements. In this study, there were subjects who used lower limb orthoses in their daily life or during practice, and ankle planter flexor spasticity was selected as a variable that affects gait. The reason for this may lie in the association between the ankle plantar flexor and the Br.S. The ankle planter flexor spasticity may be affected by spasticity in other joints. First of all, since the extent of impairment is associated with the emergence of spasticity[33], diminished ability to perform voluntary movements may affect gait despite the use of lower limb orthoses. In some cases, ankle plantar flexor spasticity may be accompanied by spasticity in other joints and it may cause gait deviations despite the use of lower-limb orthoses.

With regard to the maximum WBR on the unaffected side, in healthy individuals it can reach 94.9%, whereas in stroke patients it can reach 85%; the ability to shift the weight to the unaffected side was found to be impaired in stroke patients[34]. Similarly, in this study, the mean value was 85.39%. In relationship with total gait assessment score and the maximum WBR, the higher the total gait assessment score, the maximum WBR on the unaffected side would tend to be within the range of 80–90%. The lower the total gait assessment scores, the maximum WBR of the unaffected leg have large variation. The reason is following. Regardless the severity of lower limb paralysis, loading on the unaffected side becomes impaired. And the patients with considerable decline in lower limb functions of the affected side whose maximum WBR on the unaffected side does not reach 80–90% may be excluded because they can't reach supervised or unaided gait. In the future, to determine how the maximum WBR on the unaffected side affects gait, is it necessary to classify subjects according to the time elapsed since the onset and severity of the condition.

2. Study limitations

For objective gait assessment, a method incorporating 3-dimensional motion analysis system, an accelerometer, and a ground-reaction force sensor system is appropriate. However, in this study, we employed gait assessment forms to conveniently assess gait in a clinical setting. Several gait assessment and intervention tools tailored for stroke patients have been reported[15-19], but assessment parameters required for gait assessment in stroke patients have not been determined. It should be noted that the total scores calculated using the assessment forms that were employed in this study exhibited a correlation with physical function and walking ability. This confirmed the content validity of the assessment forms. However, it is necessary to verify whether the assessments performed using the assessment forms represents true values. Furthermore, since this is a cross-sectional study, follow-up assessments are required to confirm whether it is possible to capture the changes of gait deviations continuously.

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