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ORIGINAL ARTICLE

Determinants of Step-through Gait Pattern Acquisition in Subacute Stroke Patients

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Objectives: Stroke patients may have a step-to gait pattern during the early stages of gait reacquisition. This gait provides stability, but it is slow and inefficient. Therefore, acquiring step-through gait is desirable for better efficiency as ability improves. This study aimed to examine the relevant factors affecting the acquisition of step-through gait pattern in subacute stroke patients based on assessments of physical function at admission. **Methods:** This was a retrospective cohort study. A total of 91 patients with hemiplegic stroke, Functional Independence Measure (FIM) gait item of 4 or less on admission, and FIM gait item of 5 or greater on discharge were included. Factors necessary for the acquisition of step-through gait pattern were examined based on the motor function assessed by Stroke Impairment Assessment Set (SIAS) at the time of admission. Gait pattern was defined by the gait step length of the Tinetti Performance-Oriented Mobility Assessment at discharge. **Results:** Knee-joint extension function on the paralyzed side was determined as a factor associated with the acquisition of step-through gait pattern at discharge [odds ratio 2.24, 95% confidence interval (CI) 1.44–3.50, P<0.001]. The area under the receiver operating characteristic curve for predicting the step-through gait pattern at discharge was 0.786 (95% CI 0.676–0.896, P<0.001) for the SIAS knee joint score at admission; the optimal cut-off score being 2 or greater (sensitivity 81%, specificity 61%). **Conclusions:** Knee function on the paralyzed side in subacute stroke patients is an independent predictor for the acquisition of step-through gait pattern.

Key Words: knee joint extension; paralyzed; recovery; rehabilitation; strategy

INTRODUCTION

Stroke is the primary cause of serious long-term disability.[1)] Sequelae include motor, sensory, and cognitive impairments that can cause balance and gait problems and limit activities of daily living (ADL).[2,3)] In addition, as the risk of falling increases, the range of activities becomes smaller, and the quality of life decreases.[2,3)] Overcoming gait disorders is important for patients with stroke to improve ADL and quality of life; however, many patients are not satisfied with their acquired walking ability.[4)] In non-ambulatory patients with stroke, reacquisition of efficient gait is desirable along with walking ability.

In gait rehabilitation of patients with stroke and hemiplegia, the step-to gait pattern is generally used in the beginning of gait reconstruction, during which the stride length of the non-paralyzed side is aligned with that of the paralyzed side. In experiments with healthy participants, such a gait pattern improves stability in the left–right direction at a very slow speed,[5)] and makes sense in the early stage of gait practice for stroke patients. Although the step-to gait pattern is stable, it is a low-speed gait pattern that is also asymmetric, with a high energy expenditure and low efficiency.[6–9)] Therefore, it is desirable to acquire an efficient step-through gait. However, depending on the degree of motor dysfunction, this may be impossible. In the early stages of gait relearn-

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ing after stroke onset, knowing the likelihood of being able to achieve step-through gait in the future allows for a more efficient rehabilitation. Despite this reasoning, no study has investigated the functional factors that can predict the future acquisition of step-through gait.

Previous studies have reported that the degree of paralysis[10] and trunk function[11] are related to the acquisition of functional walking ability in stroke patients. Therefore, we hypothesized that factors necessary for the acquisition of step-through gait pattern could be predicted based on physical function at hospital admission. The purpose of this study was to retrospectively investigate the factors necessary for acquisition of step-through gait pattern in subacute stroke patients admitted to a rehabilitation hospital, based on the assessment of physical function at admission.

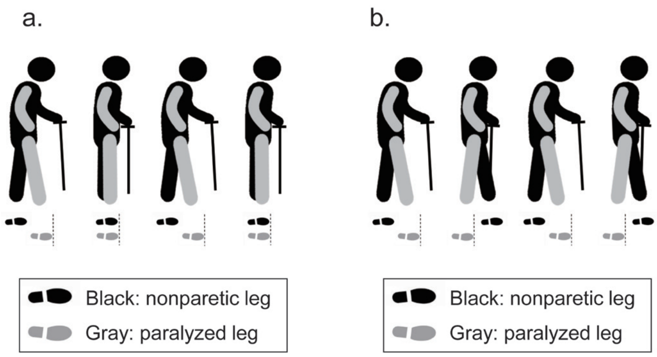

Fig. 1. Classification of walking patterns. (a) Step-to gait pattern. The toe of the paretic side does not pass the toe of the nonparetic side in the stance phase. (b) Step-through gait pattern. The toe of the paretic side passes the toe of the nonparetic side in the stance phase.

MATERIALS AND METHODS

Study Design

This was a retrospective cohort study, conducted according to the principles of the Declaration of Helsinki, and the study results were reported according to the STROBE (Strengthening Reporting of Observational Studies in Epidemiology) reporting guidelines. The study protocol was approved by the Institutional Review Board of the Tokyo Bay Rehabilitation Hospital, Japan (approval number: 238). The requirement of informed consent was waived because of the design of the retrospective study; individuals who did not opt out were included.

Study Setting and Participants

The study was conducted at the Tokyo Bay Rehabilitation Hospital, which has convalescent rehabilitation wards.[12] The participants included 130 stroke hemiplegic patients admitted to the hospital from April 1, 2018, to March 31, 2020. The inclusion criteria were: 1) hemiplegic patients with first-ever stroke; and 2) patients with a Functional Independence Measure (FIM)[13] gait item of 4 or less at admission. The exclusion criterion was patients under 20 years of age.

In the convalescent rehabilitation ward where the target patients were admitted, rehabilitation (physio-, occupational, and speech therapy) programs were conducted each day for 2–3 h per day.[12] Rehabilitation mainly consisted of repetitive, task-specific training aimed at reacquiring ADL.[14]

Study Variables

Demographic information and characteristics of the patients, including sex, age, paretic side, hospitalization duration, gait pattern, FIM,[13] and Stroke Impairment Assessment Set (SIAS),[15] were collected from patients' medical records. Walking ability at admission was determined from the walking items of the FIM,[13] which were assessed by nurses based on ADL in real-life situations. The FIM[13] is an assessment tool used to evaluate ADL. The items of this scale are scored using a seven-point scale, where 1 indicates complete dependence and 7 indicates complete independence; it consists of 13 motor subscales (13–91 points) and 5 cognitive subscales (5–35 points). In other words, a FIM score of 4 or lower for walking indicates that the patient needs assistance, and a score of 5 or higher indicates that the patient can walk. The reliability and validity of this measure have been previously confirmed in patients with stroke.[16]

Physical function at admission was obtained from the SIAS[15] assessed by a physical therapist. The SIAS[15] is a comprehensive functional assessment for stroke patients, composed of nine types of functional disorders and 22 items in total. These assessments were performed in a seated posture, and motor function items were assessed on a six-step scale, whereas muscle tonus, sensory function, trunk function, and higher brain function were assessed on a four-step scale. The SIAS is reliable and valid as a functional evaluation in stroke patients.[17,18]

The gait pattern at the time of discharge was classified into two groups according to the step length of the Tinetti Performance-Oriented Mobility Assessment (POMA) gait test.[19] The POMA is defined as a step-to gait pattern when the non-paralyzed leg does not pass the paralyzed leg (score 0) and a step-through gait pattern when the non-paralyzed leg passes the paralyzed leg (score 1) (**Fig. 1**). POMA has

Table 1. Basic attributes of target patients on admission

	All (n=130)	Unable to walk (n=39)	Able to walk (n=91)
Age (years) [a]	68.3 (13.2)	75.5 (10.1)	65.2 (13.2)
Sex (M/F)	72/58	19/20	53/38
Time from stroke onset to admission (days) [a]	35.5 (18.7)	38.8 (19.5)	34.1 (18.2)
Length of hospitalization (days) [a]	123.2 (41.4)	115.7 (45.0)	126.4 (39.6)
SIAS motor hip-flexion test [b]	2.0 (1.0)	1.0 (0.7)	2.0 (1.0)
SIAS motor knee-extension test [b]	2.0 (1.5)	0.0 (1.0)	2.0 (1.5)
SIAS motor foot-pat test [b]	1.0 (1.5)	0.0 (0.7)	2.0 (1.5)
SIAS trunk balance abdominal MMT [b]	2.0 (0.5)	0.0 (0.5)	2.0 (0.5)
SIAS trunk balance verticality test [b]	3.0 (0.5)	1.0 (0.5)	3.0 (0.5)
FIM motor items [b]	28.0 (12.0)	19.0 (5.3)	36.0 (11.5)
FIM cognitive items [b]	20.0 (7.5)	12.5 (4.3)	24.0 (7.5)

[a] Data given as mean (SD).
[b] Data given as median (interquartile deviation).
MMT, manual muscle testing

proven its reliability and validity for hospitalized stroke patients.[20] In addition, lower limb orthosis and walking stick were adjusted appropriately according to the physical function of the patient during walking exercises.

Statistical Analyses

All patients were classified into one of two groups: those who could not walk and those who could walk based on their gait FIM score of 5 at discharge. Subsequently, the following analyses were conducted to evaluate the determinants for the acquisition of step-through gait pattern in patients with a walking FIM score of 5 or higher at discharge. First, univariate logistic regression analysis was performed for selection of explanatory variables, with the gait pattern at discharge as the dependent variable and the SIAS subscore at admission as the independent variable. Subsequently, to obtain factors that influence the future acquisition of step-through gait pattern, multivariate logistic regression analysis (forward selection based on the likelihood ratio test with significance level of 0.05) was conducted in which items that showed a significant association ($P<0.05$) with gait pattern at discharge in the univariate logistic regression analysis were analyzed. The multicollinearity among the explanatory variables was evaluated a priori with a variance inflation coefficient less than 10.[21] The area under the receiver operating characteristic curve (AUC) was calculated using receiver operating characteristic (ROC) analysis, and the cut-off values were examined to obtain clinical reference values for the items extracted as influencing factors of the step-through gait pattern. The value corresponding to the largest Youden index was selected as the cut-off. The significance level was less than 5%. Statistical analysis was performed using IBM SPSS Statistics 26.0 for Windows.

RESULTS

Table 1 shows the basic attributes of the target patients at admission. The mean age of all participants (n=130) was 68.3 [standard deviation (SD) 13.2] years, the mean number of days from stroke onset to admission was 35.5 (SD 18.7) days, and the mean length of hospitalization was 123.2 (SD 41.4) days. Of these, 91 patients (70.0%) with a gait FIM score of 5 or higher at discharge had a mean age of 65.2 (SD 13.2) years, a mean number of days from stroke onset to admission of 34.1 (SD 18.2) days, and a mean length of hospitalization of 126.4 (SD 39.6) days. Furthermore, of the patients who could walk (n=91), 18 (19.8%) had a step-to gait pattern and 73 (80.2%) had a step-through gait pattern (**Fig. 2**).

Table 2 presents the results of the univariate logistic regression analysis with gait pattern at discharge as the dependent variable and SIAS subscore at admission as the independent variable. Among the items that were significant in the univariate logistic regression analysis, the explanatory variables in the multivariate logistic regression analysis were nine items related to lower limb function[22] and trunk function[11,23] that are necessary for stroke patients to acquire walking, considering confounding factors. The nine items incorporated as explanatory variables were the following SIAS subtests: hip-flexion/knee extension/plantar pad tests, deep tendon reflexes of the lower extremities, muscle tone of

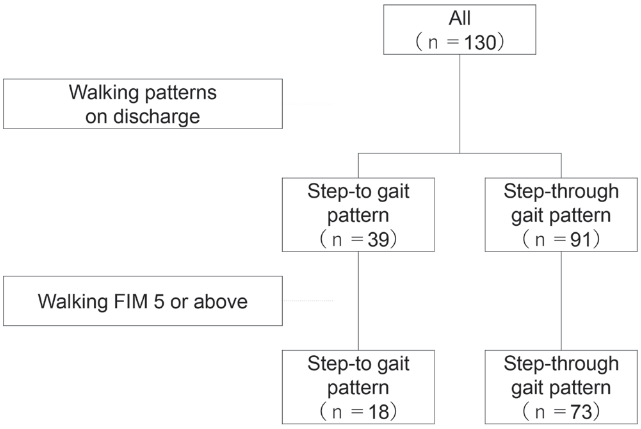

Fig. 2. Walking ability of target patients at discharge.

the lower extremities, light touch of the lower extremities, position of the lower extremities, manual muscle strength test of the abdominal muscles, and verticality test. When multicollinearity among explanatory variables was assessed with a variance inflation coefficient less than 10, no multicollinearity was detected (mean 3.7). Multivariate logistic regression analysis (forward selection) confirmed that only knee joint extension function of the paralyzed side at the time of admission was identified as a necessary determinant of the step-through gait pattern [odds ratio 2.24, 95% confidence interval (CI) 1.44–3.50, P<0.001). The result of the Hosmer–Lemeshow test was P=0.888, and the discriminant accuracy rate was 79.5%, indicating a good fit of the model.

Cut-off values were investigated using ROC analysis to obtain clinical reference values for the items extracted as determinants of the step-through gait pattern. The AUC in the ROC analysis of the knee joint extension function of the paralyzed side on admission and the gait pattern at discharge was 0.786 (95% CI 0.676–0.896, P<0.001) (**Fig. 3**). The cut-off value obtained from the Youden index was 2 points (sensitivity 0.808, specificity 0.611).

DISCUSSION

We aimed to examine the related factors affecting the acquisition of a step-through gait pattern in subacute stroke patients who could not walk independently, based on their physical function at admission. Knee joint extension function was observed to be a relevant factor.

The rate of ambulation gain in the subacute stroke patients included in this study, who could not walk independently, was 70%. Similarly, a systematic review of non-ambulatory patients admitted to a rehabilitation hospital within 1 month after stroke reported a 65% ambulation gain within 6 months.[24] Furthermore, basic attributes such as the mean age of the patients and the number of days since stroke onset were also comparable to previous studies,[24] indicating that the participants in our study were general stroke patients.

Previous studies have reported that improvement of paralyzed-side lower limb[22] and trunk function[11,23] is an important factor in improving the walking ability in stroke patients. However, the joint functions that influence the improvement of walking ability have not been clarified.[11,22,23] In the present study, the SIAS[15] was used to examine the related factors affecting the acquisition of a step-through gait pattern, which showed that the knee joint extension function on the paralyzed side is one of the factors. The knee-extension functional items of the SIAS reflect the smoothness of movement and muscle strength of the knee joint on the paralyzed side.[15] It is generally considered that the knee joint extensor muscles undergo important actions required to achieve propulsive force in the latter stage of stance.[25] In addition, step length asymmetry in chronic stroke patients is negatively correlated with driving force during the paralyzed stance phase.[7] These results were considered to reflect support in the paralyzed stance phase. In other words, it was suggested that the knee joint extension function was important for supporting the paralyzed side to acquire the step-through gait pattern.

The AUC value of the ROC analysis of SIAS knee-extension function at admission was 0.786 (P<0.001), and the cut-off value was 2 out of 6 points (sensitivity 0.808, specificity 0.611). In other words, if the patient could contract the knee extensor and lift the heel off the floor in the sitting position, but could not fully extend the knee joint, acquiring a step-through gait pattern may be possible in the future. AUC values in the range of 0.7–0.9 can be interpreted as moderately accurate.[26] Therefore, the AUC values in this study indicate moderately accurate outcomes for identifying acquisition of a step-through gait pattern. The SIAS used in the present study constitutes an observational evaluation method that can be performed without special training or tools. As a result, we considered the SIAS to be highly versatile as a criterion for predicting the future walking abilities of subacute stroke patients.

In general, it is recognized that improvement of ADL ability in stroke patients takes significant time.[27,28] Task-specific practice and repetition are important to enhance rehabilitation effects.[14] In the present study, the cut-off value of the knee-extension function on the paralyzed side can be useful for: a) predicting whether acquiring a step-through gait pat-

Table 2. Univariate logistic regression analysis of gait patterns and SIAS subitems and basic attributes (n=91)

SIAS	Odds ratio	95% confidence interval	P value
Knee-mouth test	1.92	1.24–2.99	0.004
Finger-function test	1.93	1.15–3.22	0.013
Hip-flexion test	2.11	1.35–3.31	<0.001
Knee-extension test	2.17	1.41–3.36	<0.001
Foot-pat test	2.44	1.41–4.23	<0.001
U/E DTR	3.93	1.31–11.76	0.014
L/E DTR	2.31	1.10–4.86	0.027
U/E muscle tone			0.052
L/E muscle tone	3.80	1.57–9.18	0.003
U/E light touch	1.94	1.11–3.39	0.020
L/E light touch	1.76	1.01–3.07	0.045
U/E position	2.22	1.28–3.84	0.004
L/E position	2.04	1.16–3.60	0.014
U/E ROM			0.107
L/E ROM			0.940
Pain			0.568
Abdominal MMT	2.18	1.19–3.99	0.012
Verticality test	1.92	1.02–3.61	0.043
Visuo-spatial deficit			0.340
Speech	2.12	1.10–4.08	0.025
Quadriceps MMT			0.333
Grip strength			0.472
Basic attributes			
Sex			0.796
Age			0.066
Length of hospitalization			0.054
Days to enter			0.538
Paralyzed side			0.054

U/E, upper extremity; L/E, lower extremity; DTR, deep tendon reflex; ROM, range of motion; MMT, manual muscle testing

tern during hospitalization would be possible, and b) setting an optimal walking exercise task from the beginning of the hospitalization period.

A limitation of this study is that the intervention period varied on a case-to-case basis because the time of achieving ambulation was set at the time of hospital discharge. Therefore, the results may differ because of changes in the length of hospitalization. Another limitation was the index of the step-through gait pattern, which was defined using the step length of the POMA gait test. Therefore, a quantitative evaluation of the degree of improvement in stride length was not possible. The third limitation was that the study was conducted with a relatively small sample size at a single institution. Additionally, because of the retrospective nature of the study, it was impossible to control the type and frequency of the exercises executed by the participants. The type and frequency of practice at different facilities can differ. Therefore, further verification is required to determine if similar results can be obtained. In the future, verification of the results in multiple facilities will be necessary by quantifying the step length based on engineering data and controlling the practice content and frequency. Despite these limitations, this study identified the related factors affecting the acquisition of step-through gait pattern in subacute stroke patients.

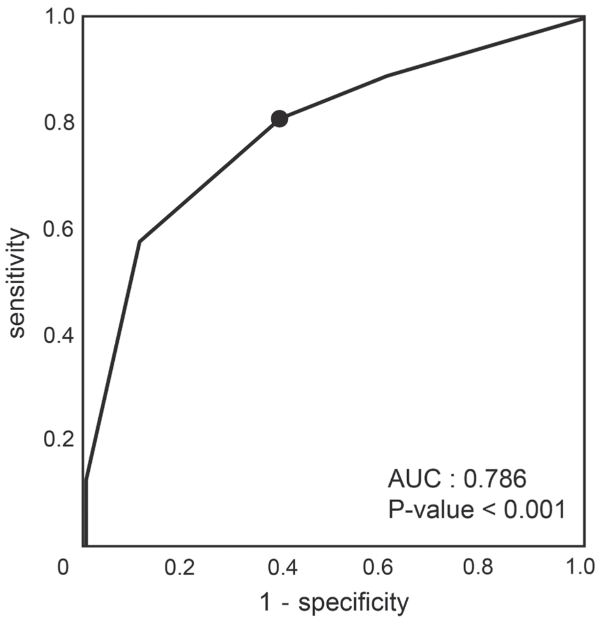

Fig. 3. Receiver operating characteristic curve of the walking pattern at discharge and knee-extension function at admission. The cut-off value of knee-extension function on the paralyzed side at admission is 2 points (sensitivity 0.808, specificity 0.611).

CONCLUSIONS

This study showed that the predictive factor for a step-through gait pattern in subacute stroke patients was knee-extension function on the paralyzed side. This finding provides information to assist the gait rehabilitation of subacute stroke patients.

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CONFLICTS OF INTEREST

The authors declare no potential conflict of interest.

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