

The relationship between bilateral knee muscle strength and gait performance after stroke: the predictive value for gait performance

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Abstract. [Purpose] The purpose of this study was to assess the relationships between bilateral knee extension strengths and gait performance in subjects with poststroke hemiparesis and to predict gait performance by the paretic and nonparetic knee extension strength. [Subjects and Methods] This was a correlational study in which 238 consecutive inpatients with poststroke hemiparesis were enrolled. Knee extensor muscle strengths in paretic and nonparetic lower limbs were measured with a handheld dynamometer, and the presence or absence of impaired gait was also determined. [Results] The mean strength in the paretic lower limb was 0.90 Nm/kg, and that in the nonparetic lower limb was 1.24 Nm/kg. Discriminant analysis classified the difference between the possibility and impossibility of gait by knee extensor muscle strength (standardized discriminant coefficient: paretic, 1.32; nonparetic, 0.55). Thus, paretic and nonparetic knee extension strengths were integrated in the strength index. A threshold level of 2.0 provided the best balance between positive and negative predictive values for the strength index. [Conclusion] The results indicated that both paretic and nonparetic knee extension strengths were related to gait performance. The strength index deduced from bilateral knee extension strengths may serve as a clinically meaningful index for rehabilitation assessment and training.

Key words: Stroke, Handheld dynamometer, Gait

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INTRODUCTION

Gait is among the most important functions affected after the occurrence of a stroke¹⁾. Three months after suffering a stroke, 25% of surviving patients remain wheelchairbound, and in 60% of subjects, walking ability and speed are markedly reduced²⁾. One of the main impairments after stroke is reduced muscle strength on the side contralateral to the brain lesion³⁾. The relation between paretic knee muscle strength on the contralateral side and gait ability after a stroke has been investigated in many studies^{1, 3–14)}. A moderate to strong relation is generally observed between knee muscle strength in the paretic limb and gait performance^{4–13)}.

However, muscle strength on the side ipsilateral to the lesion can also be affected after stroke^{3, 15)}. Harris et al.¹⁵⁾ suggested that the development of ipsilateral muscle weakness

was associated with immobility after stroke and weight loss due to swallowing difficulty and nutritional insufficiency. In addition, throughout the aging process, older people demonstrate an overall decline in muscle mass caused not by stroke but by aging^{16–18)}. This generalized loss of skeletal muscle is considered a major factor leading to the development of impairment in muscle strength for older adults¹⁸⁾. Regardless of the occurrence of stroke, lower limb weakness has been identified as an important risk factor for walking in older adults^{19–22)}. Muscle weakness in the bilateral lower limbs caused by aging may have already been increasing before a stroke²³⁾. Thus, paretic and nonparetic lower limb weakness of older stroke patients is complex as a result of the multidimensionality of the challenges caused both by stroke and aging^{24, 25)}. This muscle weakness associated with aging is most obvious in areas such as Japan, the United States, and Europe, which have dramatically aging populations^{26–28)}.

Very few studies have assessed the contribution of strength in nonparetic lower limbs to gait performance^{1, 3, 29–32)}. Furthermore, the findings are controversial: three studies^{1, 29, 31)} reported no significant relation between knee muscle strength in the nonparetic lower limb and gait performance, whereas a further three found a significant relation^{3, 30, 32)}. The association between strength and functions may be curvilinear;

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a critical amount of strength is needed for “normal” performance of specific activities³³). Above this threshold level of strength, further increases will not enhance performance of the task. Below the threshold, there should, theoretically, be a stronger relation between strength change and change in performance.

A major aim of stroke rehabilitation is optimization of the recovery of muscle strength to regain walking ability^{34–37}). However, the relation between strength in the nonparetic lower limb and gait performance has attracted much less attention, and the results are conflicting. As the threshold level of strength to predict walking independently is unknown in older stroke patients, it is difficult to predict the level of muscle strength that allows independent walking in older patients with hemiparesis. If bilateral knee muscle strength could be used to predict independent walking, training to regain gait performance would become more evidence-based in aging societies.

Therefore, this study was designed to assess the relations between bilateral knee extension strengths and gait performance in older subjects with poststroke hemiparesis and to predict gait performance by both paretic and nonparetic knee extension strength. Taking into consideration for previous studies on knee extension strength and walking ability^{3, 30, 32}), we hypothesized that there is a significant relationship between bilateral knee extensor strength and gait performance and that both paretic and nonparetic lower limb strength could be used to predict independent walking in older stroke patients. To our knowledge, this is the first study to demonstrate the predictive values of both paretic and nonparetic lower limb strength with respect to gait independency.

SUBJECTS AND METHODS

The eligibility criteria included hemiplegia of the lower extremities, absence of severe consciousness disorder, ability to sit up with a backrest for more than 30 minutes, ability to push against a dynamometer with the nonparetic lower limb after physical guidance, a period of less than 2 months since the stroke event, absence of severe cardiorespiratory insufficiency, and willingness to participate in the study.

The average value and standard deviation (SD) of normalized knee extensor strength in 20 patients with poststroke hemiplegia were assessed to determine the sample size. There is a strong relation between force as measured by equipment and body weight in strength measurements²³). The variability (relative dispersion) of the force scores was reduced by normalization against body weight. Thus, the torques (Nm) determined by force (N) and lower leg length (m) were normalized by the ratio of body weight (Nm/kg) to predict gait ability by strength measurement. The average normalized knee extensor strength in the nonparetic lower limb of the 20 subjects was 1.33 newton-meters/kg (Nm/kg; SD, 0.37 Nm/kg). For the 9 subjects who could walk independently, it was 1.51 Nm/kg (SD, 0.37 Nm/kg), and for the 11 subjects who required assistance, it was 1.18 Nm/kg (SD, 0.40 Nm/kg). Five percent of the average normalized knee extensor strength for the 9 subjects who could walk was 0.08 Nm/kg (8% difference), and the standard effect

size was 0.30. Sample size was based on a desired 90% statistical power to detect an 8% difference in normalized knee extensor muscle strength against body weight (Nm/kg), with a two-sided α of 5%. A sample size of 234 was derived by insertion of 1-power (0.90), α (0.05), and standard effect size (0.30) values into the Hulley matrix³⁸). The authors therefore planned to recruit about 234 people with poststroke hemiplegia for this study. The study was approved by the Kawasaki Municipal Tama Hospital Institutional Committee on Human Research. All subjects and their families were briefed about the aims of the study and the testing procedure prior to participation. Written informed consent was obtained from each subject. This study was performed in accordance with the Declaration of Helsinki.

Knee extension strength was assessed with a μ Tas MT-1 handheld dynamometer (ANIMA, Tokyo, Japan). The dynamometer pad is 55×55 mm, and its front side is curved to fit the shape of the areas to be measured on the extremities. The measurement range of this dynamometer is 0.1 to 999.9 N, with a recording interval of 0.1 N. A handheld dynamometer may be used to quantify maximal strength and may offer several advantages over free weights, including ease of transport, time efficiency, and low cost. The intraclass correlation coefficients, used to characterize the reliability of the strength tests using the handheld dynamometer, ranged from 0.84 to 0.99, which is considered good^{39, 40}). Furthermore, use of a handheld dynamometer provides a reliable and valid means of measuring muscle strength in patients with brain damage^{41–44}).

Prior to strength testing, the tester took the subject’s leg and guided it in the appropriate direction in accordance with the testing protocol to familiarize the subject with the feeling of pushing against the dynamometer. Strength of the knee extensor muscles was then assessed bilaterally using the μ Tas MT-1. For knee extensor assessment, subjects were seated in a hard chair with their knees flexed 90° and their arms on their thighs. The dynamometer was placed perpendicular to the leg just above the malleoli. During all tests, the dynamometer was kept stable by the examiner using both hands and/or the subject’s leg and was fixed by a belt to keep the knee flexed 90°. Subjects were told to push against the dynamometer by attempting to straighten their leg. They were asked to build force gradually to a maximum voluntary effort. They then maintained maximum effort for 5 additional seconds. Throughout the session, each subject was given consistent verbal encouragement. The limb used to start the testing was randomized.

Gait ability was precisely defined by the Functional Independence Measure (FIM) locomotion item⁴⁵). The FIM locomotion item was chosen because of its widespread use at rehabilitation facilities and ease of scoring. In this study, when the FIM locomotion item score of a subject was 6 points or more (modified independence, in which the use of a cane and orthosis was accepted for 50-m gait, or complete independence), the subject was considered to be able to walk.

To determine the association between normalized knee extensor muscle strength in paretic and strength in the nonparetic lower limb, Pearson correlation coefficients was used. Then, patients were classified into 2 groups:

Table 1. Characteristics of patients satisfying the eligibility criteria (n=238)

Age (y)	70.9 ± 10.5
Gender (n)	
Men	138
Women	100
Diagnosis (n)	
Infarction	196
Hemorrhage	42
Time post stroke at assessment (d)	8.2 ± 6.9
Paralysis side (n)	
Right	125
Left	113
Sensory disturbance (n)	
Tactile sense	87
Deep sense	19
Ataxia (n)	37
Aphasia (n)	33
Unilateral spatial neglect (n)	24
Lower leg length (m)	0.39 ± 0.04
Knee extensor muscle strength (Nm)	52.4 ± 40.7

Values are shown as the mean ± SD

those who scored 6 points or more for the FIM locomotion item and those who scored less than 6 points. Discriminant analysis was performed to identify the combination of knee extension strength of both limbs that discriminates best between possibility and impossibility of gait and to clarify the contribution of the paretic and nonparetic lower limbs to gait performance. After discriminant analysis, paretic and nonparetic knee extension strengths, adjusted by the degree of a standardized discriminant coefficient, were integrated in the strength index. The strength index was modeled as a simple regression, and parameter estimates were assessed for goodness of fit to the model: strength index = $\beta_1 X + \beta_2 Y$ (β_1 , standardized discriminant coefficient of paretic lower limb; X , normalized knee extension strength of paretic lower limb; β_2 , standardized discriminant coefficient of nonparetic lower limb; Y , normalized knee extension strength of nonparetic lower limb). The threshold level for prediction of independence was judged as the point where both the negative and positive predictive values were high⁴⁶⁻⁴⁸. All statistical procedures were carried out using SPSS software. A value of $p < 0.05$ was considered statistically significant.

RESULTS

Between January 2005 and January 2009, 238 consecutive stroke inpatients from Kawasaki Municipal Tama Hospital (Kanagawa, Japan) were enrolled in the present study. Stroke was diagnosed according to the World Health Organization definition⁴⁹. Characteristics of patients who met the inclusion criteria are presented in Table 1. The mean age of participants was 70.9 years (SD, 10.5 years). There were 138

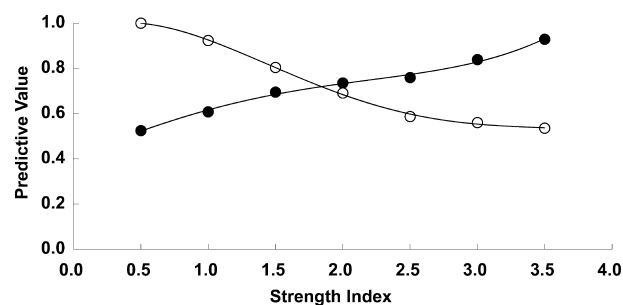


Fig. 1. Prediction of gait performance by predictive value curve. The threshold level for prediction of independence was judged as the point where both the negative (open symbols) and positive predictive values (filled symbols) were high. The curve for the negative and positive predictive values indicated that a strength index of 2.0 would provide the best balance for gait performance (positive predictive value, 0.74; negative predictive value, 0.69).

males and 100 females. Of them, 196 and 42 were diagnosed with cerebral infarction and cerebral hemorrhage, respectively, 125 patients had right hemiplegia, and 113 patients had left hemiplegia. The average time since stroke event was 8.2 days (SD, 6.9 days). Mean body weight was 57.6 kg (SD, 11.6 kg). Strength of the knee extensor muscles in the paretic lower limb of the 238 subjects in this study ranged from 0.00 to 321.0 Nm (average, 52.4; SD, 40.7 Nm). That in the nonparetic lower limb ranged from 7.1 to 336.0 Nm (average, 72.6; SD, 39.9 Nm). Strength of the normalized knee extensor muscles in the paretic lower limb ranged from 0.00 to 3.82 Nm/kg (average, 0.90; SD, 0.62 Nm/kg). That in the nonparetic lower limb ranged from 0.10 to 4.00 Nm/kg (average, 1.24; SD, 0.58 Nm/kg). The correlation coefficient (r) between normalized knee extensor muscle strength in the paretic lower limb and that in the nonparetic lower limb was 0.73 (Pearson correlation coefficient, $p < 0.0001$).

Discriminant analysis was carried out to determine which paretic and nonparetic knee extension strength had a weighted impact on differentiating between the ability and inability to walk. The discriminant analysis classified the difference between the ability and inability to walk (eigenvalue, 0.49; Wilks' lambda, 0.67; χ^2 , 93.85; df, 2; $p < 0.0001$). Two variables contributed to classification of the ability of stroke patients to walk, which was performed with a standardized discriminant coefficient (knee extensor muscle strength in the paretic lower limb, 1.32; that in the nonparetic lower limb, 0.55). Thus, paretic and nonparetic knee extension strengths were integrated in the strength index: strength index = $1.32 X + 0.55 Y$, where X is the normalized knee extension strength in the paretic lower limb and Y is the normalized knee extension strength in nonparetic lower limb. After discriminant analysis, the threshold level for prediction of independence was judged as the point where both the negative and positive predictive values were high. A threshold level of 2.0 provided the best balance between positive and negative predictive values for the strength index (Fig. 1).

DISCUSSION

In the present study, a relation between both paretic and nonparetic lower limb strength and gait performance was discovered. Our results indicated that (a) the paretic lower limb strength was correlated with the nonparetic lower limb strength, (b) both the paretic and nonparetic knee extension strengths were predictors of gait performance in older patients with poststroke hemiparesis, (c) the paretic knee extension strength affected gait performance more than the nonparetic strength, and (d) the strength indices of the paretic and nonparetic strengths combined with the weighted impact for gait performance could predict gait performance. A strength index of 2.0, meaning that the prediction of gait performance was deduced from the bilateral knee extension strengths, provides the best balance between positive and negative predictive values. About 75% of patients with a strength index of more than 2.0 could walk independently. However, 70% of patients with a strength index of 2.0 or less could not walk independently. A previous study suggested that there was a moderate to strong relation between paretic knee extension strength and gait performance⁴⁻¹³, whereas the relation between nonparetic knee extension strength and gait performance was controversial^{1, 3, 29-32}. However, the abovementioned studies recruited subjects who could walk without supervision or physical assistance and assessed gait speed as gait performance. An additional new observation in the present study was that both the paretic and nonparetic lower limb strengths affected the ability to walk independently. In our study, the predictive value of combined bilateral knee extension strength for gait independency was clearly demonstrated.

Moreover, we provided evidence indicating that paretic lower limb strength is correlated with nonparetic lower limb strength in this study. Throughout the aging process, people demonstrate an overall decline in muscle mass¹⁷. This generalized loss of skeletal muscle is considered a major factor leading to the development of impairments in muscle strength for older adults¹⁸. This muscle weakness associated with aging is obvious in regions such as Japan, the United States, and Europe, where society is dramatically aging²⁶⁻²⁸. Our results implied that throughout the aging process, older people demonstrate an overall decline in muscle mass caused not by stroke but by aging.

Although progressive resistance training is an appropriate intervention and assessment for improving gait performance and bilateral lower limb strength in older people with poststroke hemiparesis, comparatively little research has focused on the training effect of combined paretic and nonparetic lower limbs of older patients with stroke⁵⁰. Our study demonstrated the threshold level of the strength index for subjects with poststroke hemiparesis who could ambulate independently. Therefore, the period required to reach the threshold level in resistance training programs may be estimated by further research. In the future, a prospective cohort study is necessary to identify predictors of recovery of independent gait ability after stroke. In addition, isometric evaluation with a handheld dynamometer utilizes a mode of contraction different from that used in training, as isotonic contraction is most commonly used for exercise training.

Thus, use of a handheld dynamometer is limited by lack of specific training. Future studies need to assess whether handheld dynamometers can measure changes in strength after resistance training with the same precision as those measured by isotonic testing.

Engardt et al.⁵¹ noted that patients learned to use the nonparetic leg to compensate for the weakness of the paretic leg in the early phase of rehabilitation. In previous studies, patients might have already learned to use the nonparetic leg to compensate for the weakness of the paretic leg in their gait because a long period had passed since the onset of stroke^{1, 3, 29-32}. It is still difficult to predict the contribution of both the paretic and nonparetic lower limb strengths to gait performance in older patients with poststroke hemiparesis. Thus, we recruited patients in the subacute stage of stroke. However, about 25% of patients with a strength index of more than 2.0 could not walk independently. When patients with a knee extension strength over the threshold level are unable to walk independently, learning to use the nonparetic and paretic legs might be a useful strategy for the patient to adopt. Activities of daily living are considered behavioral chains of component actions; such chains have been learned and performed since childhood⁵². A patient with hemiplegia cannot walk by means of the behavioral chains used by a healthy person and thus has to learn new behavioral chains to walk independently. There is a growing body of evidence indicating that locomotor treadmill training with partial body-weight support may be an effective method of improving gait quality in the acute stage of stroke^{53, 54}. The intensity of resistance training and skill training can be decided by the threshold level of strength determined in this study. Future studies are needed to assess whether changes in muscle strength measured using a handheld dynamometer can reflect the ability of a subject to perform activities of daily life after resistance and skill training.

It has been reported that stroke patients cannot perform at higher angular velocities due to spastic antagonist restraints⁵⁵. However, isometric strength has been shown not to be affected by antagonist muscle spasticity⁵⁶. Our investigation evaluated the relationship between isometric bilateral knee extension strength and gait performance; as a result, antagonist muscle spasticity would have had little effect on agonist muscle strength. However, because spasticity of knee extensor and flexor muscles in stroke patients was not examined in this study, further research is needed to investigate the relationship between lower limb strength and spasticity and gait performance.

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