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博　士　論　文

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Does assessing error in perceiving postural limits applying Functional Reach Test predict likelihood of falls in hospitalized stroke patients?

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Objective: To investigate the relationship between errors in perceiving postural limits and falls in hospitalized hemiplegic patients and to determine whether this relationship is useful for identifying patients at high risk for falls.
Design: Observational study.
Subjects: Seventy-six hemiplegic patients who were admitted to a rehabilitation hospital.
Methods: Error in perceiving postural limits was defined as the difference between the estimated maximum reach and actual reach distances, and its relationship to falls during hospitalization was investigated. Other measurements included Functional Ambulation Category, Brunnstrom's recovery stage, sensory disturbance, fear of falling, and the Japanese version of the Montgomery-Åsberg Depression Rating Scale (MADRS-J).
Results: For the multiple fall group, the error in estimated distance (EED) was significantly greater than that for the zero/single fall group ($p<0.01$). Stepwise logistic regression analysis showed that EED (odds ratio: 1.2, 95%CI: 1.1-1.4, $p<0.01$) and MADRS-J scores (odds ratio: 1.1, 95%CI: 1.0-1.3, $p<0.05$) were correlated with multiple falls. According to the receiver operating characteristic curve for EED, the cut-off value for discriminating multiple fallers was 6.3 cm (sensitivity: 81.0%, specificity: 78.2%, area under the curve: 0.8).
Conclusions: The results suggest that assessing error in perceiving postural limits by measuring the maximum reach of the non-affected side of hemiplegic patients is one way to identify those who are at high risk for falling.

Introduction

Falls in elderly people increase the risk of traumatic injuries, including bone fracture. Stroke is one of the greatest risk factors for falling, and the risk of facture is higher than in stroke patients than in healthy elderly people (1-3). Studies have shown falling incidences of between 14% and 39% during hospital stays (4-6), and the risk of femoral neck fracture increases after the fourth fall (7). With regard to the length of time from admission to falls at rehabilitation units, Suzuki et al. (8) reported that the number of people who fell and the number of falls were the highest within one week of admission.

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Therefore, identifying high-risk patients for bone fracture soon after hospitalization is important in preventing falls. Currently in Japan, only patients within two months of onset and those requiring intensive rehabilitation are admitted to rehabilitation units, and stroke patients can stay for up to six months. In rehabilitation units at geriatric hospitals, the mean hospital stay for stroke patients has been reported to be about five months in Japan (9), and it is important to develop a convenient screening tool to predict falls during this period.

Fall-related factors for the elderly are generally classified into intrinsic and extrinsic fall factors (10). Intrinsic fall factors include physical factors, such as walking speed (11,12), leg muscle strength (13,14), and balance (15,16), psychological factors, such as fear of falling (17,18), and cognitive factors, such as attention deficit (19). However, stroke patients have additional risk factors, such as visuospatial impairment, distorted body image and disease-specific problems. We constantly perceive and assess our own physical performance when interacting with the surrounding environment under various conditions, and this ability is also an important factor. Gibson (20) explained this complementary relationship between physical movements and the surrounding environment using the term "Affordance", and it has been reported that aging affects the mutual perception of the surrounding environment and body images. In clinical settings, some patients state that they lost their balance when they failed to reach for something that they judged to be reachable.

The objectives of the present study are to: determine the relationship between error in perceiving postural limits and falls among hemiplegic stroke inpatients; and to elucidate whether assessing perception errors is useful in identifying high-risk patients.

Methods

Subjects and Design

Subjects were 76 hemiplegic patients admitted to rehabilitation units who were either within two months of onset or required intensive rehabilitation. Inclusion criteria were: (i) 24 points on the Mini-Mental State Examination (21); (ii) no severe higher brain function disorders; and (iii) able to stand unassisted for at least one minute. Exclusion criteria were: (i) other neurologic disorders; (ii) severe visual impairment; and (iii) leg surgery within six months. In each subject, physical function, ADL levels, fear of falling, depression and error in perceiving postural limits were assessed. Each item was assessed within one week from the time of admission, and the number of falls over five months was recorded and analyzed. Subjects were divided into four groups: the zero fall group and single/multiple fall group to predict falls during hospitalization; and the zero/single fall group and multiple fall group to identify multiple fallers who are at greater risk for bone fracture.

All subjects provided informed consent to participate in the study, and the protocol for the study was approved by the Ethics Review Board of Kio University School of Medicine and Nishiyamato Rehabilitation Hospital.

Measurements

Number of falls during hospitalization

The present study was conducted over a 2-year period from April 2005 to March 2007. The number of falls during five months of hospitalization was determined from accident reports and information provided by the rehabilitation units. The present study adapted Tinetti and colleagues' definition of falls (22): an episode of unintentionally coming to rest on the ground or a lower surface that was not the result of dizziness, fainting, sustaining a violent blow, loss of consciousness, or other overwhelming external factor.

Assessment of physical function

The following physical functions were assessed: non-affected side Functional Reach distance, Functional Ambulation Category (23), lower-extremity Brunnstrom's recovery stage, and leg sensory disturbance. We designed and produced a measurement device, as shown in Figure 1, to measure non-affected Functional Reach distance according to the method of Duncan et al. (24). The measurement device comprised a sliding bar placed inside a horizontal tube, and the height of the tube is adjustable. Each subject was instructed to stand with their feet about shoulder width apart, and the height of the sliding bar was set at the height of the acromial process. Next, the subject was instructed to raise the non-affected arm to form a 90° angle with the body, completely extend the elbow, and pronate the forearm. Then, with the arm fully extended, the subject was instructed to push the sliding bar using the tip of the middle finger as far as possible without changing the base of support. The maximum distance of the sliding bar was recorded as Functional Reach distance. This measurement was repeated three times and averaged. Patients who wore leg braces were allowed to wear their leg braces during the test. Leg sensory disturbance was measured in four grades using the following ordinal scale: Normal (0 points), Mild (1 point: mild superficial or deep sensory disturbance), Moderate (2 points: moderate superficial or deep sensory disturbance) and Severe (3 points: severe superficial or deep sensory disturbance or lack of sensation).

Assessment of fear of falling and depression

We used the Visual Analogue Scale, which assesses pain severity, in order to determine fear of falling at the limit of postural stability. A 10-cm line was drawn, and the left end was labeled "not at all afraid" and the right end was labeled "unbearably fearful". Fear of falling was assessed at the same time as measurement of Functional Reach. Each subject was asked to mark the level of fear during maximum anterior reach using the scale.

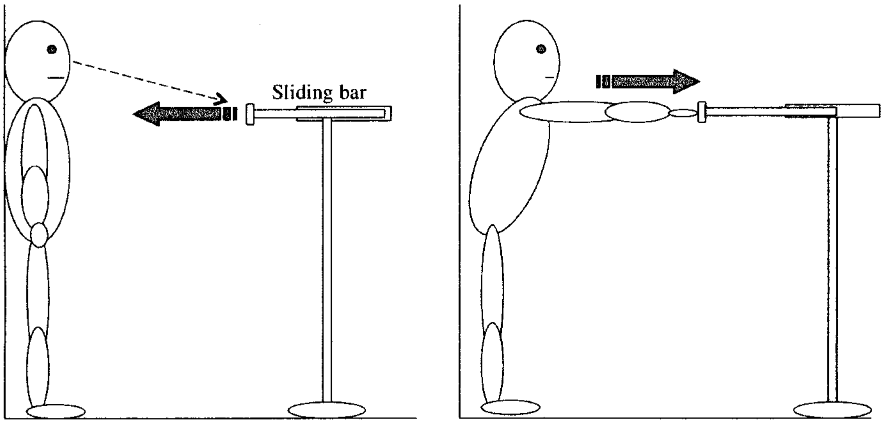

Figure 1. Estimation of functional reach distance and measurement of actual functional reach distance.
1) Height of the measurement device was set to the level of the acromial process.
2) The sliding bar was then moved closer to visually estimate functional reach (Left figure).
3) After fully extending the arm and placing the sliding bar at the tip of the middle finger, the subject is instructed to push the sliding bar as far as possible to measure functional reach (Right figure).
4) The difference between estimated and actual reach distances is recorded as an absolute value to assess errors in perceiving forward postural limits.

Depression was assessed using the Japanese version of the Montgomery-Åsberg Depression Rating Scale (MADRS-J) (25).

Assessment of error in perceiving postural limits

Assessment of error in perceiving postural limits was measured as the difference between the actual maximum reach distance and the visually estimated maximum reach distance, and defined as error in estimated reach distance (EED).

Estimated reach distance was measured by bringing the sliding bar closer, and the subjects were instructed to indicate when the sliding bar was first considered reachable (Figure 1). Distances were measured by first impression, and subjects could not change their answer. The subjects were allowed to wear their glasses. After estimating the maximum reach distance, Functional Reach was measured, and EED was calculated by subtracting the estimated distance from the actual distance. EED values were recorded as absolute values to indicate the degree of perception error.

Statistical analysis

Subjects were classified into several groups with respect to the presence or absence of one or more falls (zero fall group, single/multiple fall group) and multiple falls (zero/single fall group, multiple fall group). The independent sample t-test was used to compare EED, Functional Reach distance, fear of falling score, Functional Ambulation Category score and MADRS-J score, while Mann-Whitney U test was used to compare Brunnstrom's recovery stage and sensory disturbance score. For calculation of predictive values for one or more fall and multiple fall, and extraction of fall-related factors adjusted for the effects of other assessment items, stepwise logistic regression analysis was performed using two models (dichotomous dependent variable: whether patient fell or not, and whether patient fell multiple times or not). Furthermore, the cut-off value of EED for discriminating the risk for falls and identifying multiple fallers was determined, and in order to determine which cut-off values would be more useful in predicting falls, two types of analyses were carried out using receiver operating characteristic (ROC) curves. The cut-off value for each model was the point closest to the upper left-hand corner of the curve, which was the most suitable indicator for differentiating the single/multiple fallers and multiple fallers. For statistical analysis, JMP (SAS Institute, Japanese version 6.0.3) was used and the level of significance was set at $p<0.05$.

RESULTS

Table I shows subject demographics. The mean (SD) age of the subjects was 68.7(12.0) years (range: 25-91 years). The mean (SD) time since stroke was 6.1 (4.7) months (range: 1-22 months), and 38 patients (50%) who suffered a stroke more than six months. Fifteen patients (19%) were able to walk independently, and the other patients used wheelchairs. The median Barthel index score was 80 points (range: 50-100 points). During observation period, falls satisfying the criteria of the present study occurred in 37 of the 76 subjects (49%), and there were 16 single fallers (43%) and 21 multiple fallers (57%).

Table I Subject Demographics (n=76).

Characteristics	n(%)	Mean±SD (range)
Age	NA	68.7±12.0 (25-91)
Sex		
Female	31(41)	NA
Male	45(59)	NA
Diagnosis		
Infarction	42(55)	NA
Hemorrhage	30(39)	NA
Other	4(6)	NA
Time since onset (mo)	NA	6.1±4.7 (1-22)
Affected side		
Left	36(47)	
Right	40(53)	

Abbreviations: NA, not applicable; SD, standard deviation.

Table II shows the various scores for each group. No significant differences were seen in the degree of sensory disturbance, Functional Reach distance, Functional Ambulation Category score and Visual Analogue Scale score for fear of falling between the zero fallers and single/multiple fallers or between the zero or single fallers and multiple fallers. The mean (SD) EED was 10.5 (4.7) cm, and the EED for the single/multiple faller group was significantly greater than that for the zero fallers ($p<0.01$) and the EED for the multiple fallers was significantly greater than that for the zero or single fallers ($p<0.01$). The average MADRS-J score for the multiple fallers was significantly greater than that for the zero or single fallers ($p<0.05$). Table III shows the results of stepwise logistic regression analysis. Two models were prepared for analysis. The dichotomous dependent variable for Model 1 was the presence or absence of falls, and the dependent variable for Model 2 was the presence or absence of multiple falls. As independent variables, age and gender-adjusted Functional Reach distance, EED, score for fear of falling, leg sensory disturbance, Brunnstrom's Recovery Stage and Functional Ambulation Category score were used. With Model 1, EED (odds ratio: 1.2, 95%CI: 1.0-1.3, $p<0.01$) and sensory disturbance (odds ratio: 1.9, 95%CI: 1.1-3.4, $p<0.05$) were extracted as fall predictors (R2=20%), and with Model 2, EED (odds ratio: 1.2, 95%CI: 1.1-1.4, $p<0.01$) and MADRS-J score (odds ratio: 1.1, 95%CI: 1.0-1.3, $p<0.05$) were extracted as fall predictors (R2=24%). Regression discriminant analysis was performed to predict falls; with Model 1, 41 of the 76 patients were identified with a correct predictive value of 69.8%, and with Model 2, 27 of the 76 patients were identified with a correct predictive value of 73.7%. In terms of the ROC curve for EED, the cut-off value for differentiating fallers from zero fallers was 6.1 cm (sensitivity: 68.6%, specificity: 82.0%, area under the curve: 0.7), and the cutoff value for differentiating multiple fallers from zero or single fallers was 6.3 cm (sensitivity: 81.0%, specificity: 78.2%, area under the curve: 0.8) (Figure 2).

Table II Subject Characteristics by Falling Status (n=76)

Variables	All Subjects	Zero fallers	Single / multiple fallers	Zero / single fallers	Multiple fallers
BRS	5 (4-5)	5 (4-5)	4 (3-5.5)	5 (4-5)	4 (3-6)
Sensory impairment	1 (0-2)	0 (0-1)	1 (0-2)	0 (0-2)	1 (0-2.5)
FR (cm)	22.3 (7.5)	42.5	34.2	22.9 (6.9)	21.1 (9.0)
EED (cm)	6.5 (4.9)	5.0 (4.7)*	8.0 (4.8)*	5.2 (4.5)⁺	9.7 (4.6)⁺
MADRS-J	5.3 (6.4)	4.67 (5.2)	6.0 (7.5)	4.3 (4.7)⁺	8.0 (9.2)⁺
Fear of fall (cm)	3.1 (3.1)	2.9 (3.3)	3.3 (2.9)	2.9 (3.2)	3.5 (2.9)
Barthel Index	80 (70-90)	80 (75-95)	75 (70-87.5)	80 (70-95)	75 (70-80)
FAC	3 (3-4)	3 (3-4)	3 (3-4)	3 (3-4)	4 (3-3.5)

NOTE. Values are mean (SD) or median (25-75 percentile).
*Significant difference between zero fallers vs. single/multiple fallers.
⁺ Significant difference between zero/single fallers vs. multiple fallers.

DISCUSSION

The results of our study indicate that EED may be useful in identifying stroke patients at high risk for falls. In addition, by comparing two ROC analyses, it was possible to determine the area under the curve for a model identifying multiple fallers and a cut-off value (6.3 cm) with high levels of sensitivity and specificity, thus suggesting that the present method is useful in predicting patients who fall multiple times within the first five months of hospitalization. In addition to EED, MADRS-J was extracted as a prognosticator, and this supported a prior study documenting the correlation between depression and falls in stroke patients (1). Based on the relationship between falls and EED and MADRS-J score, the risk of falling appears to be high in patients with high EED and greater depressive symptoms.

Table III Stepwise Logistic Regression Analysis Results.

Models	Level of Significance	% Correct Prediction	Correctly Predicted Fallers	Coefficient	OR	95%CI	*P*
Model 1	<0.001	69.8%	28/37				
EED				0.2	1.2	1.0-1.3	<.01
Sensory				0.7	1.9	1.1-3.4	<.05
Model 2	<0.001	73.7%	17/21				
EED				0.2	1.2	1.1-1.4	<.01
MADRS-J				0.1	1.1	1.0-1.3	<.05

NOTE. Only risk factors statistically significant in the final models are shown. All models were adjusted for age and sex. Risk factors for subjects who fell once or more (Model 1) and those who fell multiple times (Model 2).

Several studies have measured estimated reach distance in healthy individuals.
Fischer (26) reported that the average estimated bias in anterior reach distance for healthy individuals was about 5 cm. In the present study, the average EED was 6.5 cm, and when compared to healthy individuals, hemiplegic patients may have greater error in perceiving postural limits. When asked to estimate reach distance without moving the body trunk, healthy individuals tend to slightly overestimate (26-29). While it has been reported that perceived reachability is influenced by psychological and environmental factors, its mechanism has not been clarified. As hemiplegic patients tend to form distorted body images and fail in forming proper images of body movements, the difference between estimated and actual distances may be greater when compared to healthy individuals.

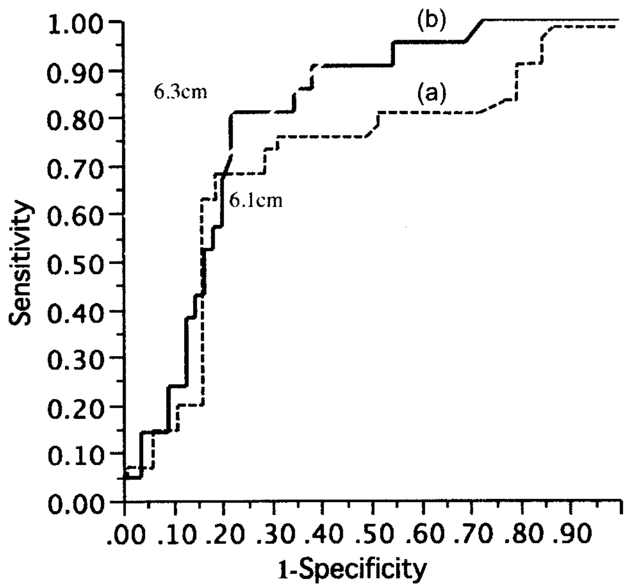

Figure 2 (a) ROC curves for EED to discriminate one or more fallers.
(b) ROC curves for EED to discriminate multiple fallers.

In hospital settings, functional limitations related to falls and fall risk are not as clear in stroke patients. In community-dwelling elderly people, decreases in functional reach distance have been correlated to increases in falls (30). However, in the present study, Functional Reach distance was not extracted as a significant factor, and there were no significant differences in Functional Reach distance between faller and non-faller group. The results suggest that Functional Reach distance is not correlated with falls in stroke patients. In the present study, except for EED and MADRS-J, many factors were not shown to correlate with falls, and in the future, it will be necessary to investigate assessment factors that maximize discrimination power.

The limitations of the present study were patients with relatively favorable physical function were enrolled, and misjudgment of movements was not the cause of all falls. In order to determine whether the present technique is a highly accurate screening tool for predicting multiple fallers, it will be necessary to verify the results in a well-designed study.

Clinical Messages

- Hemiplegic stroke patients who incorrectly estimate their posutural limits by 6.3cm are more likely to fall multiple times.
- Assessing error in perceiving postural limits of hemiplegic patients is one way to identify those who are at high risk for falling.

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