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Walking velocity and modified rivermead mobility index as discriminatory measures for functional ambulation classification of chronic stroke patients

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Background: The cut-off values of walking velocity and classification of functional mobility both have a role in clinical settings for assessing the walking function of stroke patients and setting rehabilitation goals and treatment plans.
Objective: The present study investigated whether the cut-off values of the modified Rivermead Mobility Index (mRMI) and walking velocity accurately differentiated the walking ability of stroke patients according to the modified Functional Ambulation Category (mFAC).
Methods: Eighty two chronic stroke patients were included in the study. The comfortable/maximum walking velocities and mRMI were used to measure the mobility outcomes of these patients. To compare the walking velocities and mRMI scores for each mFAC point, one-way analysis of variance and the post-hoc test using Scheffe's method were performed. The patients were categorized according to gait ability into either mFAC = VII or mFAC ≤ VI group. The cut-off values for mRMI and walking velocities were calculated using a receiver-operating characteristic curve. The odds ratios of logistic regression analysis (Wald Forward) were analyzed to examine whether the cut-off values of walking velocity and mRMI can be utilized to differentiate functional walking levels.
Results: Except for mFACs III and IV, maximum walking velocity differed between mFAC IV and mFAC V ($p < 0.01$), between mFAC V and mFAC VI ($p < 0.001$), and between mFAC VI and mFAC VII ($p < 0.05$).

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The cut-off value of mRMI is > 26.5 and the area under the curve is 0.87, respectively; the cut-off value for comfortable walking velocity is > 0.77 m/s and the area under the curve is 0.92, respectively; also, the cut-off value for maximum walking velocity is > 0.92 m/s and the area under the curve is 0.97, respectively. In the logistic regression analysis, the maximum walking velocity (> 0.92 m/s, OR = 22.027) and mRMI (> 26.5 scores, OR = 10.283) are able to distinguish mFAC = VII from mFAC $\leq$ VI.
Conclusion: The cut-off values of maximum walking velocity and mRMI are recommended as useful outcome measures for assessing ambulation levels in chronic stroke patients during rehabilitation.

Keywords: Discriminatory factors; modified Functional Ambulation Category; modified Rivermead Mobility Index; stroke; walking speed.

Introduction

The walking function of stroke patients is closely related to mobility, walking velocity, cardiovascular endurance, dynamic balance, motor skill, and muscular strength in the lower limb of the affected side.[1,2] Recovery of functional mobility and walking function is the priority of rehabilitation after stroke.[3] Therefore, in clinical settings physical therapists assess the gait and mobility of stroke patients using standardized assessments such as walking velocity[4] and the modified Rivermead Mobility Index (mRMI).[5]

The modified Functional Ambulation Category (mFAC), which uses a seven-point Likert scale, is a tool for clinical assessment of walking ability in stroke patients that uses a Functional Ambulation Classification system. The mFAC has been shown to have a high correlation ($r = 0.88$–0.90) with walking velocities (comfortable/maximum) and mRMI performance scores.[6] In other words, as the functional gait ability is recovered in stroke patients, the physical measurements of walking velocity and mRMI are increased. In one correlation study,[6] there were significant differences in walking velocity and mRMI scores, as reflected by the mFAC scores between stroke patients (from III to V points) and the independent ambulatory group (VI and VII points). Tsang *et al.*[7] found significant differences in average walking velocity between different mFAC scores (III–VII) of 62 stroke patients, and they determined that mFAC could accurately classify the ambulation levels. However, results from these studies focused on only the statistical differences in mRMI and walking velocities in stroke patients. It is not clear whether the mFAC score may be determined based only on values of mRMI and walking velocities.

Previous studies proposed the cut-off values of walking velocities for community ambulation. Three levels of community ambulation have been classified with the following thresholds: most limited community walkers (25 m/min), limited community walkers (35 m/min), and community walkers (48 m/min).[8] Previous literature determined cut-off values of community ambulation levels according to the walking velocity (indoor ambulation: > 0.4 m/s, limited community ambulation: 0.4–0.8 m/s, and community ambulation: > 0.8 m/s).[9] The cut-off values of walking velocity and classification of functional mobility both have a role in clinical settings for assessing the walking function of stroke patients and setting rehabilitation goals and treatment plans.

The aim of this study was to quantitatively categorize two different mFAC groups using cut-off values of walking velocity and mRMI. This study investigated whether the cut-off values of walking velocity and mRMI can be discriminatory measures of functional ambulation for stroke patients categorized into two groups, mFAC = VII and mFAC $\leq$ VI. In this study, we used the definitions of discrimination suggested in previous literature.[10] Lord *et al.*[10] stated that when the community-walking ability was classified into four levels, the walking velocity increased as the level of gait ability increased, and the walking velocity decreased as the level of gait ability decreased. As a result, walking velocity was deemed to be a suitable measurement for discriminating the four levels of community walking categorized by a self-questionnaire. The hypotheses of this study are as follows: (1) there will be significant differences in walking velocities and mRMI in different mFAC categories, (2) there will be significant differences in walking velocities and mRMI between the two groups, and (3) the cut-off values of walking velocity and mRMI will be discriminatory indicators for mFAC.

Methods

Participants

This study was a cross-sectional investigation conducted with 91 patients with chronic hemi-paralysis caused by stroke. Our participants consisted of both inpatients and outpatients at *M* hospital. The study design was blinded for assessment and intention-to-treat analysis. Participants had cognitive function scoring of no less than 23 points on the Mini-Mental State Examination-Korean version (MMSE-K).[11] The participants did not have a lower motor neuron lesion or an orthopedic disease in the lower limbs. Ninety one chronic stroke patients initially enrolled on the basis of these inclusion criteria. General characteristics collected via hospital records and interviews included age, time since onset, diagnosis, location of paralysis, and MMSE-K scores. The procedures of this study were approved by Konyang University Institutional Review Board (IRB Approval No. 2017-066) and the participants signed the informed consent form prior to study participation.

Assessment procedures

Outcome assessment was performed by two physical therapists with more than 15 years of experience (SH, DS) in stroke treatment and diverse evaluation methods including the study's evaluation methods. The assessments were completed within 30 min, and the investigators provided a break for all participants between the two assessments to minimize the effect of fatigue.

Measures

The outcome measures in this study were composed of two standardized mobility assessments including the mFAC and a seven-point scale for classifying the gait ability of participants. The mobility measures were: (1) comfortable walking velocity (CWV, m/s) and maximum walking velocity (MWV, m/s), as measured by the modified 5-m Ambulation Velocity Test, which includes a 2-m acceleration and deceleration interval, for a total distance of 9 m, which helped minimize the necessary space and lessened the mental burden and stress of participants.[12] All subjects were asked to stop at the marked end point, and were instructed to walk as fast as they could three times while maintaining the safety. The examiner recorded the time taken to walk from the end of the 2-m acceleration mark to the start of the 2-m deceleration mark. (2) The mRMI score is determined based on eight questions about mobility. The inter-rater reliability of mRMI [intra-class correlation coefficient (ICC) $= 0.98$][5] and test–retest reliability (ICC $= 0.99$) have been established in stroke patients.[7]

To determine each participant's ambulation ability, the primary physical therapist (SH) evaluated the mFAC[13] with the following criteria. Depending on the need for physical assistance, ambulation ability was scored as I point (unable to perform ambulation but able to maintain sitting position for 1 min with assistance, or unable to keep the position for 1 min without hand or back support); II points (unable to perform ambulation but able to maintain sitting position for 1 min without supporting self with hands or back support); III points (need someone to provide constant and reliable assistance for ambulation); IV points (need someone to provide constant or intermittent assistance for ambulation); V points (need verbal cues and supervision for ambulation); VI points (able to perform indoor ambulation on level ground); and VII points (able to perform outdoor ambulation). The mFAC test–retest reliability (concordance rate $= 93\%$, weighted kappa coefficient $= 0.97$) was reported in stroke patients.[7]

The participants were assigned to groups according to walking levels using the mFAC. The mFAC is a seven-point scale that classifies the walking function level. In the current study, functional gait ability (i.e., outdoor gait ability) was defined depending on whether a patient could perform activities such as climbing the stairs, walking on uneven levels, etc.; the effect of this ability on social outcomes was not considered. If the participants could perform outdoor ambulation, they were categorized into an mFAC $=$ VII group (high-level ambulation group, HG). If the tasks could not be performed, the categorization was mFAC $\leq$ VI (low-level ambulation group, LG). In this study, the participants' functional walking levels were separated into two groups with mFAC $=$ VII points (HG) and $\leq$ VI points (LG).[14] All the participants were unaware of their classification.

Statistical analysis

Descriptive statistics were computed for data, including the data regarding general characteristics, mFAC points, mRMI score, and comfortable and maximum walking velocities. For comparing the walking velocities and mRMI scores for each mFAC point, we used one-way analysis of variance and performed the post-hoc test using Scheffe's method. The Mann–Whitney test was conducted to compare the walking velocities and mRMI scores of HG and LG. For the comparative analysis of effect size, Cohen d was utilized. The cut-off value was produced by using the receiver-operating characteristic curve (ROC curve) for the differentiation of walking velocity and mRMI for functional walking levels. In the area under the ROC curve (AUC), $0.5 < \text{AUC} \leq 0.7$ indicates lower precision, $0.7 < \text{AUC} \leq 0.9$ indicates mid-level precision, $0.9 < \text{AUC} < 1.0$ indicates high precision, and $\text{AUC} = 1.0$ indicates complete test.[15] With respect to the cut-off values of walking velocity and mRMI, the odds ratio (OR) in logistic regression analysis (Wald Forward) was used to estimate the discriminative validity of functional walking levels. All data were analyzed using IBM SPSS Statistics version 20.0 (IBM Corp., Armonk, NY, USA) and the statistical significance level was set at $\alpha = 0.05$.

Table 1. General characteristics.

Variable	Value (s)
Gender: Male/Female (n)	51/31
Age (years): Mean (SD)	59.09 (11.74)
Diagnosis: infarct/hemorrhage (n)	58/24
Hemiplegic side: Right/Left (n)	44/38
Duration (month): Mean (SD)	16.43 (12.24)
MMSE-K (score): Mean (SD)	26.20 (1.54)
Mobility status: (n)	
Unaided	34
Single-point cane	33
Quadripod	12
Walker	3
mFAC (point): Mean (SD)	5.35 (1.35)
mFAC III/IV/V/VI/VII (n)	10/13/18/20/21
mRMI (score): Mean (SD)	26.32 (6.20)
Comfortable walking velocity (m/s): Mean (SD)	0.59 (0.27)
Maximum walking velocity (m/s): Mean (SD)	0.75 (0.36)

Note: SD: Standard deviation, MMSE-K: Mini Mental State Examination-Korean version, mFAC: modified Functional Ambulation Category, and mRMI: modified Rivermead Mobility Index.

Results

Subjects' characteristics

Six participants dropped out during the examination period due to a deteriorating health condition or discharge from the hospital. Ultimately, 82 participants were included in the study analysis. The general characteristics of the participants are provided in Table 1. The participants were within the mFAC range of III–VII.

Walking velocity and mRMI in different mFAC categories

The walking velocities and mRMI scores of 82 chronic patients of mFAC categories III–VII were measured (see Table 2). The mean CWV increased from 0.17 m/s [standard deviation (SD): 0.4] for mFAC III to 0.86 m/s (SD = 0.15) for mFAC IV, 0.50 m/s (SD = 0.11) for mFAC V, 0.75 m/s (SD = 0.08) for mFAC VI, and 0.86 m/s (SD = 0.15) for mFAC VII. In addition, the mean MWV increased from 0.26 m/s (SD = 0.6) for mFAC III to 0.38 m/s (SD = 0.04) for mFAC IV, 0.60 m/s

Table 2. Walking velocities and mRMI scores of patients of different mFAC categories.

	mFAC = III ($n = 10$)	mFAC = IV ($n = 13$)	mFAC = V ($n = 18$)	mFAC = VI ($n = 20$)	mFAC = VII ($n = 21$)
Comfortable velocity (m/s)	0.17 ± 0.04	0.30 ± 0.01	0.50 ± 0.11[a]	0.75 ± 0.08[b]	0.86 ± 0.15[c]
Maximum velocity (m/s)	0.26 ± 0.06	0.38 ± 0.04	0.60 ± 0.12[a]	0.88 ± 0.11[b]	1.20 ± 0.21[c]
mRMI (score)	17.0 ± 3.68	20.54 ± 2.66	27.56 ± 3.65[a]	28.55 ± 3.31	32.33 ± 3.74[c]

Note: mRMI: modified Rivermead Mobility Index. [a]Significant difference between mFACs IV and V ($p < 0.01$). [b]Significant difference between mFACs V and VI ($p < 0.001$). [c]Significant difference between mFACs VI and VII ($p < 0.05$). p was based on one-way ANOVA (post-hoc test by Scheffe's method).

Table 3. Comparison of walking velocities and mRMI scores in HG (mFAC = VII) and LG (mFAC ≤ VI).

Variable	Mean ± SD (min, max)		Z	p-Value	Cohen d
	HG (mFAC = VII, $n = 21$)	LG (mFAC ≤ VI, $n = 61$)			
mRMI	32.33 ± 3.74 (26, 40)	24.66 ± 5.63 (13, 34)	5.05	< 0.001	1.23
Comfortable velocity (m/s)	0.87 ± 0.15 (0.66, 1.31)	0.49 ± 0.23 (0.12, 0.98)	5.70	< 0.001	1.39
Maximum velocity (m/s)	1.20 ± 0.21 (0.87, 1.54)	0.60 ± 0.26 (0.19, 1.23)	6.36	< 0.001	1.65

Note: mRMI: modified Rivermead Mobility Index; mFAC: modified Functional Ambulation Category; HG: high-level ambulation group (mFAC = VII); and LG: low-level ambulation group (mFAC ≤ VI).

Table 4. Sensitivity and specificity of walking velocity and mRMI for discriminating functional walking levels.

Variable	Cut-off value	AUC (95% CI)	p-Value	Sensitivity	Specificity
mRMI (score)	> 26.50	0.87 (0.79, 0.95)	< 0.001	95% (20/21)	62% (38/61)
Comfortable velocity (m/s)	> 0.77	0.92 (0.86, 0.98)	< 0.001	90% (19/21)	88% (54/61)
Maximum velocity (m/s)	> 0.92	0.97 (0.93, 1.00)	< 0.001	85% (18/21)	93% (57/61)

Note: mRMI: modified Rivermead Mobility Index; and AUC: area under the receiver-operating characteristic curve.

(SD = 0.12) for mFAC V, 0.88 m/s (SD = 0.11) for mFAC VI, and 1.20 m/s (SD = 0.21) for mFAC VII. There were significant differences in both velocities between patients of mFAC IV and those of mFAC V ($p < 0.01$), between patients of mFAC V and those of mFAC VI ($p < 0.001$), and between patients of mFAC VI and those of mFAC VII ($p < 0.05$).

The mean mRMI score increased from 17.0 (SD = 3.68) for mFAC III to 20.54 (SD = 2.66) for mFAC IV, 27.56 (SD = 3.65) for mFAC V, 28.55 (SD = 3.31) for mFAC VI, and 32.33 (SD = 3.74) for mFAC VII. There were statistically significant differences in the mRMI scores between patients of mFAC IV and mFAC V ($p < 0.001$) and between those of mFAC VI and mFAC VII ($p < 0.05$).

Comparison of mobility outcomes between groups

The results of the mRMI performance score and comfortable and maximum velocities are shown in Table 3. Between the HG and LG groups, there were significant differences in mRMI scores, CWVs, and MWVs (all $p < 0.001$).

Cut-off value, AUC, sensitivity, and specificity

The mRMI cut-off value, sensitivity, and specificity were > 26.5 scores, 95%, and 62%, respectively. The CWV cut-off value, sensitivity, and specificity for functional walking distinction were > 0.77 m/s, 90%, and 88%, respectively. The MWV cut-off value, sensitivity, and specificity were > 0.92 m/s, 85%, and 93%, respectively (Table 4). With regression coefficients, the mRMI value (> 26.5 scores, OR = 10.283) was able to distinguish between the mFAC categorizations (HG and LG) (Table 5). However, MWV (> 0.92 m/s, OR = 22.027) was the most effective value for discriminating between LG (mFAC ≤ VI) and HG (mFAC = VII).

Table 5. Discriminatory measures analysis of cut-off values of walking velocity and mRMI for functional ambulation.

Score	Regression coefficient	Wald	Odds ratio	95% CI	p-Value
Comfortable velocity > 0.77 m/s	1.40	0.98	4.07	0.25–66.00	0.323
mRMI > 26.5	2.33	5.60	10.28	1.49–70.92	0.018
Maximum velocity > 0.92 m/s	3.09	4.80	22.02	1.39–350.41	0.028

Note: mRMI: modified Rivermead Mobility Index.

Discussion

This study investigated whether the cut-off values of mRMI and walking velocities can differentiate the mFAC scores of stroke patients who were divided into two groups based on the mFAC classification of their functional walking levels. As expected, our results found that there were significant differences between HG and LG in the mean ± SD mRMI score (32.33 ± 3.74 and 24.66± 5.63), CWV (0.87 ± 0.15 m/s and 0.49 ± 0.23 m/s), and MWV (1.20 ± 0.21 m/s and 0.60 ± 0.26 m/s). Our study demonstrated that the cut-off values of mRMI (26.5 score, OR = 10.283), CWV (0.77 m/s, OR = 4.07), and MWV (0.92 m/s, OR = 22.03) accurately discriminated mFAC scores between patients of HG (mFAC = VII) and LG (mFAC ≤ VI). The MWV and mRMI were more suitable assessments to classify walking function levels than CWV. The cut-off values of MWV (0.92 m/s, OR = 22.03) had the highest distinguishing power among the assessments evaluated. Additionally, the walking velocities and modified mRMI scores of patients of different mFAC categories were investigated, with particular focus on the outcomes which showed that MWV could differentiate between patients of mFAC IV and those of mFAC V, between patients of mFAC V and those of mFAC VI, and between patients of mFAC VI and those of mFAC VII with robust statistical power.

It is noteworthy that the CWV and MWV were significantly different between mFAC IV and mFAC V, between mFAC V and mFAC VI, and between mFAC VI and mFAC VII. This result showed that walking velocities may be the discriminatory variable for chronic stroke patients belonging to an mFAC higher than IV. However, no variable was significantly different between mFAC III and mFAC IV. This failure to identify the low mFAC is a consistent limitation in the previous study,[7] which reported the walking velocities of acute stroke patients of mFAC categories ranging from III to IV from different hospitals. The small number of stroke patients included in mFAC III and mFAC IV may account for these results compared to the results observed for patients of other categories. Overall, all variables might not be sensitive to differentiate between mFAC III and mFAC IV in the chronic stroke patients.

The rationale for the score of VII as the cut-off value of the mFAC score is based on the probability of community ambulation without falling. Our categories emphasized reduced ambulation, especially outdoors, as that correlates to a greater factor of debilitation based on a study of 40 people with stroke.[16] Therefore, we decided that the achievement of walking indoors with/without assistance versus walking independently outdoors is the best criteria for defining the overall gait ability (such as climbing stairs, walking on uneven levels, etc., and it was not extended to the social outcome).

Our findings were similar to those of preceding studies. The mean walking velocity within the different mFAC categories was shown to have an increasing trend from mFAC III (0.11 m/s, SD = 0.03) to mFAC IV (0.17 m/s, SD = 0.07), mFAC V (0.30 m/s, SD = 0.13), mFAC VI (0.70 m/s, SD = 0.29), and mFAC VII (0.82 m/s, SD = 0.19), in a study of 62 acute stroke patients. In another study[6] which examined the reliability and validity of mFAC, the mRMI score and walking velocities within each mFAC category were reported to be significantly different. As the mFAC improved from III to V, the average walking velocities (comfortable and maximum) increased from 0.16 m/s and 0.25 m/s in mFAC III to 0.50 m/s and 0.58 m/s in mFAC V, with enhancement of mRMI demonstrating functional mobility. Likewise, this trend was also observed between 0.76 m/s and 0.89 m/s in mFAC VI and between 0.88 m/s and 1.12 m/s in mFAC VII, respectively.[6]

Focusing on sensitivity and specificity, the mRMI showed a sensitivity of 95%, corresponding to the probability of dividing those with mRMI of > 26.5 among 21 participants in the HG, and a specificity of 62%, corresponding to the probability of correctly classifying those with mRMI of ≤ 26.5 among 61 participants in the LG. On the other hand, MWV showed higher specificity (93%) than mRMI, and CWV showed high accuracy in both sensitivity (90%) and specificity (88%). If a stroke survivor has mRMI of > 26.5, CWV of > 0.77 m/s, and MWV of > 0.92 m/s, a physical therapist will consider that the person is able to ambulate outdoors (high walking level), it helps to confirm the level of walking function. We considered that only the results of sensitivity and specificity were difficult to determine the implications. However, it has been reported that higher ambulation velocity leads to better mobility, and stroke survivors' ambulation activities are almost unlimited if they can ambulate freely.[10,13,17]

According to the cases of Tsang *et al.*[7] of initial stroke patients' hospitalization and discharge, the AUC level of mRMI was identified similarly (AUC = 0.79), and the cut-off value of > 20 was slightly inconsistent with the present findings. The mean score (SD) of mRMI was 26.62 (6.2) in chronic stroke patients in this study, and was 20.6 (9.3) at admission in acute stroke patients in Tsang *et al.*'s[7] prospective study. The inconsistent findings might be explained by the fact that there were differences in the post-stroke period of the participants and differences in study design. In Tsang *et al.*'s study,[7] the assessments were performed in hospital settings with assistance and monitoring, without any actual experience of community ambulation. However, our study included outpatient experiences in community ambulation.

Our results of walking velocities are consistent with those of previous studies. An *et al.*[18] reported that walking velocity (OR = 9.20) was the most powerful determinant variable of community walking among several assessments including the Berg Balance Scale, walking distance, and the Fugl–Meyer assessment. A previous study stated that walking velocity is a strong factor for predicting the level of community walking.[10] In accordance with previous studies, the results of this study suggested that maximum walking velocity (OR = 22.03) is a superior clinical assessment to discriminate between different categories of functional ambulation (HG and LG).

The research findings by Lord *et al.*[10] suggest that the FAC does not reflect the real community ambulation levels. However, Hill *et al.*[19] suggested that to achieve a successful gait within the community, at least FAC = VI, the equivalent of mFAC = VII, is necessary. The use of only mFAC is not sufficient to assure community ambulation ability. The mRMI describes the patient's mobility to perform an activity,[5] and walking velocity (comfortable/maximum) is a valid measure for identifying therapy effectiveness in stroke patients.[10] These results support the findings of this study, which suggest the physiotherapist can be better informed of the stroke patients' prognosis for functional walking levels during rehabilitation based on the walking velocity scores compared to mFAC alone.

Study limitations

Despite the clear findings of this study, it has several unavoidable limitations. This study supports the applicability of dichotomized walking velocity and mRMI score in chronic stroke patients. However, the application of walking velocity and mRMI is limited to acute stroke patients. In addition, although the participants were from subsidy-supported rehabilitation hospitals, their functional gait ability varied, and they required assistive tools or support for walking. This requirement may be associated with a fall history, which could lead to a loss of confidence to walk actively.[20] Therefore, to advance and validate our results, a study should be conducted in the future reporting on factors pertaining to gait ability and the need to identify a clinical variable that can especially discriminate between patients of mFAC III and those of mFAC IV.

Conclusion

In conclusion, this study demonstrated that the cut-off values of walking velocity and mRMI are able to discriminate between two groups within mFAC (HG and LG). As these measures of mobility are easy to assess in clinical settings, the dichotomized walking velocity and mRMI are useful for examining the walking ability in a population with chronic stroke. Future research is required to identify the cut-off values of additional measures of mobility in populations with neurological disorders.

Conflict of Interest

The authors declare no conflicts of interest.

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Author Contributions

All the authors contributed to the conception and design of the study, data analysis, and interpretation. Ji Young Lim, Seung Heon An, and Dae-Sung Park drafted the manuscript and revised it critically and provided approval for the submission to publication.

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