

Correlation of Curved Walking Ability with Straight Walking Ability and Motor Function in Patients with Hemiplegia



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Purpose: In real life there are both straight-paths and curved-paths. To evaluate walking ability of both kinds, a figure-8 walking test (F8WT) was developed. The aim of this study was to validate the measure in hemiplegic patients with walking difficulties and to identify correlations of curved walking ability with straight walking ability, motor function, and walking performance ability.

Methods: Twenty subjects participated in this study. Curved walking was measured by a F8WT. Straight walking ability was measured by a 10-meter walking test (10MWT). Dynamic balance ability was measured by timed up and go (TUG) tests. Walking performance ability was measured using a modified motor assessment scale (MMAS). Motor function was measured by the Fugl-Meyer assessment (FMA) scale. Data were analyzed using Pearson correlation analysis. Linear regression analyses were performed to explore other functional tests in mobility ability by F8WT time, 10MWT (dependent variable).

Results: There was a significant positive correlation of F8WT time with 10MWT and TUG. There was a significant negative correlation of F8WT time with MMAS and FMA-coordination. There was a significant positive correlation of 10MWT with TUG. There was a significant negative correlation of 10MWT with MMAS and FMA-coordination. The F8WT time for curved walking ability was attributed to 10MWT for straight walking ability as 94% level of contribution.

Conclusion: The results suggest that the F8WT is a good instrument for measuring walking ability because there is a robust correlation of F8WT time with 10MWT, TUG, MMAS, and FMA-coordination in hemiplegic patients who, after stroke, have a mobility deficiency.

Keywords: Curved walking, Straight walking, Hemiplegia

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1. Introduction

There are many instruments for measuring locomotion after stroke. For example, there is a 10-meter walking test (10MWT), a 6-meter walking test, a 6 minute walking test, and functional ambulation categories (FAC).¹⁻³ Some tests could be written on observing patient walking.

Most tests have been designed to measure only straight walking ability. However, it is necessary to measure multiple walking abilities.⁴ The timed up and go (TUG) test⁵ can be measured on curved-paths partially, and the Emory functional ambulation profile (E-FAP)⁶, and the dynamic gait index (DGI)⁷

can measure curved walking ability. In spite of simply turn in walking, the tests also could be measured one direction. But, in the newly developed figure-8 walking test (F8WT), curved-paths and straight-paths are combined. Thus, it is possible to measure walking abilities necessary for independence and for activities of daily living. The curved pathway of the F8WT involves clockwise and counter-clockwise direction.⁴ Walking clockwise and counter-clockwise for weight distribution are different. Walking clockwise, we can maintain balance during walking using the lateral side of the inner leg. But walking counter-clockwise is different. Straight walking showed a distribution of the medial-lateral side in both inner and outer legs equally.⁸ Since

hemiplegic patients after a stroke have walking ability limitations because of asymmetrical weight distribution on both legs, locomotion of hemiplegic patients can be tested on curved pathways.⁹

There are different walking tests for curved and straight walking and for gait characteristics and body weight distribution. Compared with curved walking, straight walking showed that the inner leg had a shorter stride length than the outer leg. When doing curved walking, body weight distribution moves toward the inner leg and there is increased stance time of the inner leg.^{10,11} In a previous study, it was reported that straight walking and curved walking ability of Parkinson's patient is different than for a normal person. In particular, there was a difference in step length and stride length during curved walking.¹² Most hemiplegic patients had limited mobility, but the walking test method did not reflect motor skill.

In a study of older people using the F8WT, falls almost always occurred when legs were crossed during walking.⁴ When older people walk on a curved pathway, most of all is easy to fall in older people when the leg is crossed. It is possible to measure curved walking ability. F8WT was good instrument to estimate falling possibility. Previously, it was reported that correlations with F8WT steps (number of steps taken) and fear of falling had a statistically significant positive correlation. Thus the more F8WT steps are increased, the more falling is increased.⁴

Until now, there were only a few studies that investigated curved walking ability in patients with hemiplegia. Few studies applied the F8WT with hemiplegic patients to investigate whether curved walking ability correlated with straight walking ability. The purpose of this study was to correlate, in stroke rehabilitation patients, curved walking ability with straight walking ability and motor function, in order to improve walking ability through training that includes curved walking and straight walking.

II. Method

1. Subjects

The twenty subjects of this study were diagnosed as having a stroke in a hospital located in Jeollabuk-do and Gwang-ju. The inclusion criterion were as follows: (1) hemiplegia due to stroke (2) subject is following physiotherapist instructions well with

scores >24 on the mini-mental state examination-Korean version (MMSE-K) (3) score >3 on the FAC scale; (4) no unilateral neglect and no vision deficiency. The duration of testing subjects ranged from 3 to 48 months. All subjects understood the purpose of this study and provided written consent which was translated into English in Children Hospital of Los Angeles. The general characteristics of subjects who participated in this study is shown in Table 1.

Table 1. General characteristics of subjects (n=20)

	Characteristics	n(%)
Gender	Male	5 (25%)
	Female	15 (75%)
Affected side	Left	8 (40%)
	Right	12 (60%)
Causes	Infarction	15 (75%)
	Hemorrhage	5 (25%)
Time since onset (month)*		16.1±13.2
Age (year)*		68.4±8.1
Weight (kg)*		59.4±10.5
Height (cm)*		159.2±8.8

* Values are mean±SD

2. Experimental method

1) Test & Measurement

(1) Figure-8 walking test (F8WT)

This test was designed to measure curved walking ability. Prior to The F8WT performance, the F8WT was verbally explained and directly demonstrated. The F8WT total length was 1.5 m and width was 1.2 m (Figure 1). Participants were instructed to stand midway between the obstacles, facing outward from the plane of the obstacles. The participants were instructed to begin walking at their usual pace when ready, choosing the direction of the figure-8 walking path around the obstacles, and then to stop and return to the starting position. A stopwatch was used to measurement total time taken (sec).⁴

(2) 10 m walking test (10MWT)

The 10MWT is an instrument to measure straight walking ability. It measures the time taken (sec) to walk 10-meter. The total walking distance is 14 m; 2 m was allowed for acceleration and deceleration. We measured the time taken to walk 10 m.¹³ The measurement was done three times. The mean was used in analyses.

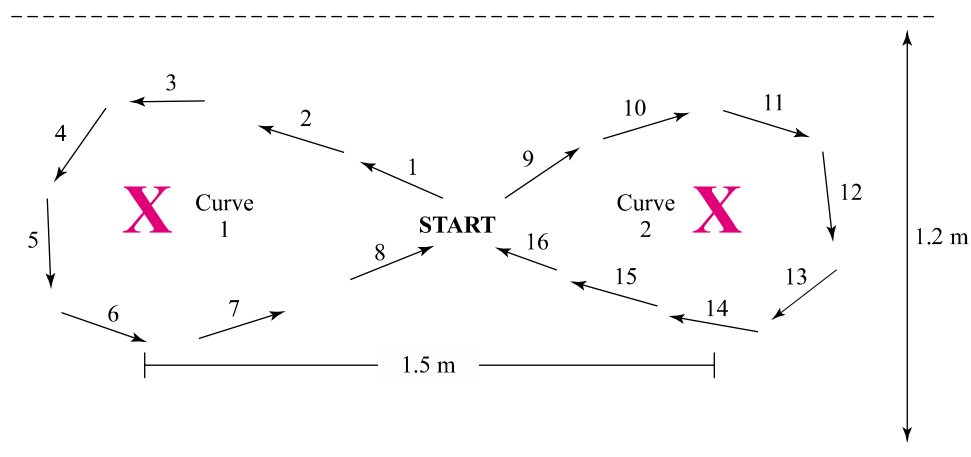


Figure 1. Figure-8 Walking Test (F8WT).

(3) Timed up and go (TUG) test

This test was designed to measure dynamic balance ability.⁵ Physiotherapists recorded the time (sec) taken to complete a task that started with the subject in a sitting position on a chair. Subjects were asked to turn around 3 m and then sit on a chair. Subjects practiced the task once, and then were tested three times. The mean of the three values was used in analyses.

(4) Modified motor assessment scale (MMAS)

This test was designed to measure walking performance ability.¹⁴ The MMAS consists of 8 components related to motor function and 1 component related to muscle tone. Thus there were 9 total items. Among these, we used only a single item to test walking performance ability. The scale of walking item score was consisted of 6 from 1 (score). After three measurements, the maximal score was used in analyses.

(5) Fugl-Meyer assessment (FMA)

The FMA was developed to measure motor function after stroke. This scale consists of five components. Each component – joint mobility, pain, sensory, balance, motor function of upper extremities, and motor function of lower extremities – was divided into subsections. Each of the components was separated by three grade. If the test was not attempted, the subject received a score of 0. If the test was partially completed, the score was 1. If the test was completed, the score was 2.¹⁵ The lower extremities item of all components was only measured. It consists of motor function (hip, knee, ankle) and coordination components, with a total possible score of 26. Each of the components was practiced three times with a physiotherapist.

After three measurements, the maximal score was used in analyses.

3. Data analysis

The data were analyzed using SPSS version 12.0. To correlate values for the components of F8WT, 10MWT, TUG, MMAS, FMA-HKA, and FMA-coordination tests, the data were analyzed by Pearson correlation analysis. To determine correlations between independent variables and dependent variables (F8WT time, 10MWT), data were analyzed by linear regression. The criterion for statistical significance (α) was 0.05.

III. Results

1. General characteristics of subjects

There were 5 males (25%) and 15 females (75%). The affected side was the left in 8 (40%) and the right in 12 (60%). The cause of injury was cerebral infarction in 15 (75%) and hemorrhage in 5 (25%). The mean age of participants was 68.4 years the mean time since onset was 16.1 months. The mean weight of participants was 59.4 kg the mean height of participants was 159.2 cm (Table 1).

2. F8WT time, 10MWT, TUG, MMAS, FMA (HKA, coordination) values of subjects

The mean F8WT time was 21.37 (sec). The mean 10MWT time was 24.17 (sec). The mean TUG time was 27.40 (sec). The mean MMAS score was 3.95. The mean FMA-HKA score was 17.20. The mean FMA-coordination score was 3.80 (Table 2).

Table 2. F8WT time, 10MWT, TUG, MMAS, FMA (HKA, coordination) values of subjects

Variable	Means±SD
F8WT time (sec)	21.37±11.90
10MWT (sec)	24.17±16.29
TUG (sec)	27.40±19.05
MMAS (score)	3.95±0.69
FMA-HKA (score)	17.20±4.58
FMA-coordination (score)	3.80±1.06

F8WT: Figure-8 Walking Test
 10MWT: 10-Meter Walking Test
 TUG: Timed Up and Go Test
 MMAS: Modified Motor Assessment Scale
 FMA-HKA: Fugl-Meyer Assessment-Hip, Knee, Ankle

3. Pearson correlation of F8WT time with 10MWT, TUG, MMAS, FMA-HKA, & FMA-coordination

There was a significant positive correlation of F8WT time with

10MWT ($r = 0.97$) and TUG ($r = 0.71$) and a significant negative correlation of F8WT time with MMAS ($r = -0.83$), and FMA-coordination ($r = -0.49$). 10MWT was positively correlated with TUG ($r=0.68$). There was a significant negative correlation of 10MWT with MMAS ($r = -0.78$) and FMA-coordination ($r = -0.53$)(Table 3).

4. Multiple regression of F8WT time, 10MWT, TUG, MMAS, FMA-HKA, FMA-coordination.

We used linear regression analysis to measure the effects of F8WT time on 10MWT, TUG, MMAS, FMA-HKA, and FMA-coordination. It was measured in coefficients (B) of independent variables to dependent variables and in modified R square (R^2). The F8WT time for curved walking ability was attributed to 10MWT ($R^2 = 0.94$) and MMAS ($R^2 = 0.95$). The 10MWT for straight walking ability was attributed to F8WT independently (Table 4).

Table 3. Pearson correlation of F8WT time with 10MWT TUG, MMAS, FMA-HKA, FMA-coordination

Measurement	10 MWT	TUG	MMAS	FMA-HKA	FMA-coordination
F8WT Time	0.97*	0.71*	-0.83*	-0.71	-0.49*
10MWT		0.68*	-0.78*	-0.14	-0.53*

* $p < 0.05$
 F8WT: Figure-8 Walking Test
 10MWT: 10-Meter Walking Test
 TUG: Timed Up and Go Test
 MMAS: Modified Motor Assessment Scale
 FMA-HKA: Fugl-Meyer Assessment-Hip, Knee, Ankle

Table 4. Multiple regression of F8WT time, 10MWT, TUG, MMAS, FMA-HKA, FMA-coordination

Dependent variable	Independent variable	B	S.E	Beta	T
F8WT time	10MWT	0.51	0.08	0.70	6.07*
	TUG	0.06	0.04	0.93	1.42
	MMAS	-3.83	1.60	-0.22	-2.44*
	FMA-HKA	0.16	0.14	0.04	0.84
	FMA-coordination	-0.93	0.77	-0.08	-1.20
10MWT	F8WT time	1.41	0.23	1.04	6.07*
	TUG	-0.03	0.07	-0.33	-0.39
	MMAS	1.44	3.10	0.06	0.46
	FMA-HKA	-0.21	0.23	-0.06	-0.93
	FMA-coordination	-0.20	1.35	-0.01	-0.15

* $p < 0.05$
 F8WT: Figure-8 Walking Test
 10MWT: 10-Meter Walking Test
 TUG: Timed Up and Go Test
 MMAS: Modified Motor Assessment Scale
 FMA-HKA: Fugl-Meyer Assessment-Hip, Knee, Ankle

IV. Discussion

Hemiplegic patients after a stroke have many problems with walking. These problems cause limitations in their walking ability. In real life, the limitations are not just in walking. A reliable instrument that can reflect the real environment around us has not yet been developed.¹⁶ But, the F8WT applied to older people proved to be an effective instrument. Effective evaluation of F8WT can reflect circumstances of real life walking challenges.⁴

In real life, we walk on both straight-paths and curved-paths. It has been said that curved walking is a more useful evaluative test than straight walking to evaluate walking skill.¹² A study related to walking showed that walking skills can be different depending on the shape of the walking pathway.¹¹ In other words, straight walking ability and curved walking ability reflect different styles of movement.¹¹

The F8WT measures real walking ability. It is a good instrument to measure curved walking ability. Intraclass correlation coefficients (ICCs) for inter-rater reliability were 0.90 (0.71~0.97) for time. ICCs for intra-rater reliability were 0.84 (0.62~0.94) for time.⁴

To investigate correlations of F8WT time with 10MWT, TUG, MMAS, FMA-HKA, and FMA-coordination in lower-extremity (L/E), we used Pearson correlation analysis. There was a significant positive correlation between F8WT time and 10MWT and TUG times. The greater the F8WT time, the greater the 10MWT or TUG time. That means that curved walking ability is correlated with straight walking ability and dynamic balance. The test procedures for the F8WT include straight and curved-paths. During walking in curved-paths, it was necessary to maintain balance more and more.¹⁷ Hess et al.⁴ reported that older people with good straight walking ability were also better at curved walking. That finding is consistent with our study results. Because there was a correlation between straight walking ability and curved walking ability, F8WT can be used to assess walking ability of stroke patients in the clinical setting. The F8WT may be able to provide information complementary to the information obtained from straight walking ability measured in stroke patients.⁴ Mild slowing during the straight-paths become short steps, uneven and hesitant steps rounding the corner of the figure-8,⁴ pace changes with every change of path direction, markedly slower speed of

gait.¹⁸ Thus it is difficult to maintain dynamic balance during walking.¹⁹

Our results indicate that correlations of F8WT time with MMAS and FMA-coordination represented a significant negative correlation. That means that the greater the increase in F8WT time, the greater the decrease in MMAS and FMA-coordination scores. In turn, curved walking ability is correlated with walking performance, coordination ability in L/E. Walking along a curved pathway implies a different pattern of muscle activation than straight walking.¹² Walking performance needs to play to interact with our body. Actually, walking along curved-paths involves a complex interplay between the different parts of our body.²⁰ The measurement of MMAS was showed to have a ceiling effect. Because all participants are able to walk, the MMAS might be preferable to measuring higher levels of mobility in the later stages of rehabilitation or in mildly impaired stroke patients. In particular, in L/E coordination, such a finding suggests that coordinated movements might be an effective approach to assist recovery of curved walking ability by stroke patients.²¹ A previous study reported that coordinated movement leads to enhanced functional ability of the impaired limb.²²

Our findings showing correlations of 10MWT with TUG, MMAS, FMA-HKA, and FMA-coordination in L/E, were significant positive correlations between 10MWT and TUG. There were significant negative correlations between 10MWT and MMAS and FMA-coordination. The more the increase 10MWT, the more the increase in TUG. The more the increase in 10MWT, the more the decrease in MMAS or FMA-coordination. That means straight walking ability is correlated with dynamic balance ability. Another study showed a significant correlation between walking speed and stability of balance.²³ Limited locomotion due to poor balance has been declined in walking ability in real life.²⁴ Lee²⁵ reported that the correlation between TUG and FIM was significant. During stance phase of walking, medial-lateral balance is maintained with one leg while keeping progression going. This is why straight walking ability is correlated with dynamic balance.

The F8WT time for curved walking ability was attributed to 10MWT as 94% level of contribution, MMAS as 95% level of contribution. The 10MWT for straight walking ability was attributed to F8WT as 94% level of contribution independently. Thus, curved walking ability and straight walking ability are very

highly correlated with each other. In the future, when evaluating walking ability of stroke patients, F8WT may need to be included in stroke rehabilitation. F8WT for curved walking ability may be useful in both the clinical setting and at home for monitoring the evolution or the efficacy of treatment. Curved walking training can help to improve walking ability in stroke rehabilitation.

The limitation of this study is related to small sample size which restricts the ability to generalize the findings to a general population of stroke patients. A future study is necessary to compare balance and motor ability between curved walking training and straight walking training after an intervention.

V. Conclusion

This research was done to investigate correlations of F8WT time with 10MWT, TUG, MMAS, FMA-HKA, and FMA-coordination. There was a statistically significant positive correlation of F8WT time with 10MWT and TUG. There was a statistically significant negative correlation of F8WT time with MMAS and FMA-coordination. The F8WT time for curved walking ability was attributed to 10MWT for straight walking ability as 94% level of contribution. The findings of this study support the idea that F8WT is a useful instrument for measuring walking ability in hemiplegic patients with movement disabilities. The measurement of walking performance using F8WT in clinical settings may provide information on the walking ability of hemiplegic patients after stroke.

Author Contributions

Research design: Lim JH

Acquisition of data: Lim JH

Analysis and interpretation of data: Lim JH

Drafting of the manuscript: Lim JH, Seo SK

Administrative, technical, and material support: Lim JH, Seo SK

Research supervision: Park JS

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