Determinants of Maximum Walking Speed in Hemiparetic Stroke Patients

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SUZUKI, K., NAKAMURA, R., YAMADA, Y. and HANDA, T. *Determinants of Maximum Walking Speed in Hemiparetic Stroke Patients.* Tohoku J. Exp. Med., 1990, **162** (4), 337-344 — The time necessary to walk 10 m with the fastest speed, the sway path of the center of feet pressure in station, and the isokinetic strength for knee extension of each side were examined in 29 hemiparetic stroke patients. The maximum walking speed of the patients was related to the sway path and the isokinetic muscle strength of affected side. The patients could be divided into two groups based on their sway path. The determinants of the maximum walking speed in the unstable group were the sway path and the isokinetic muscle strength of the both sides, whereas that in the stable group was only the isokinetic muscle strength of affected side. ——— maximum walking speed; hemiparesis; isokinetic strength; sway path

Recent studies have shown that the postural control in station and muscle strength of the affected lower extremity are closely related to the walking speed in hemiparetic stroke patients (Hamrin et al. 1982; Dettmann et al. 1987; Bohannon 1989).

Measurement of maximum walking speed for 8 or 10 m distance has been used to document walking capacity and to predict functional state in neurologically impaired patients including strokes (Wade et al. 1987; Nakamura et al. 1988). For instance, there is a linear correlation between the maximum walking speed for 10 m and the distance being walked at preferred speed for 3 min in stroke patients (Yamada et al. 1990), and also the maximum walking speed could be used to predict patients' activities of daily life in outpatient clinic (Sajiki et al. 1989).

Itoh et al. (1988, 1989), examining the relation between maximum walking speed and variables presumed to be determinants of walking capacity in healthy male adults, reported that the maximum walking speed was influenced by height, body weight, age, standing balance and muscle strength of the lower extremities. They pointed out that the reduction of maximum walking speed in the elderly was mainly due to the muscle weakness of lower extremities and the instability of station.

Then, there remains a question whether the similar relations between the maximum walking speed, and the standing balance and the muscle strength in hemiparetic stroke patients exist or not. In this study we analyzed the relations between the stability of station and the muscle strength of lower extremities, and the maximum walking speed in hemiparetic stroke patients.

MATERIALS AND METHODS

Twenty nine hemiparetic stroke patients, 20 male and nine female, participated in this study. Sixteen were paretic on the right and 13 on the left (Table 1-A). All patients could walk without any aids over 10 m at the examination.

The time required to walk 10 m as fast as possible on flat floor bounded by two tapes was measured using a digital stopwatch (Nakamura et al. 1985). The patient began to walk 3 m before the starting line and the timing commenced as soon as the patient's swing leg crossed the starting line and ended when the patient's swing leg passed over the finish line. The trial was performed three times successively and the fastest record was used as data.

As a measure of stability in station, the length of the center of feet pressure for 10 sec in station, was examined using a force platform (9807Y9 system; Kistler, Winterthur, Switzerland) and a digital computer (PC-9801F; NEC, Tokyo). The apparatus and methods were already reported in details (Mojica et al. 1988). The patient stood on the center of force platform with eyes open and feet apart 10 cm. The position of the center of feet pressure was sampled every 10 msec for 10 sec. The total length of the center of feet pressure approximated by the sum of the distances between successive instantaneous two sampling points was referred to the sway path in this study.

The maximal isokinetic strength for the knee extension of each side was measured by using a dynamometer (Cybex II; Lumex New York, NY, USA). The patient was examined in sitting on the chair with the hip and the knee flexed at 90 degrees and with the leg hanging over the edge of chair. The dynamometer arm was attached to the leg at the ankle. The isokinetic strength for knee extension from 90 to 0 degrees with angular velocity of 30 degrees/sec was measured and the peak torque was read out. The measurement was first performed on the non-affected side, then on the affected side. Three trials were carried out with more than 30 sec intertrial intervals and the highest value was used as data in each patient.

TABLE 1. *Demographic and walking variables in 29 hemiparetic stroke patients*

	Mean	Range	S.E.
A Age (years)	57.8	40-70	7.9
Height (cm)	160.4	145-174	7.1
Body weight (kg)	59.9	41.0-73.1	8.2
Time since onset (weeks)	16.5	5.7-30.0	6.8
B Max. walking speed (m/min)	52.9	3.6-125.0	37.4
Sway path (cm/10 sec)	32.8	15.3-63.5	12.2
A-ISK-S (kg•m)	4.13	0-10.62	4.00
N-ISK-S (kg•m)	9.87	3.17-16.13	3.68

A-ISK-S, isokinetic strength of the affected side;

N-ISK-S, isokinetic strength of the non-affected side.

RESULTS

Table 1-B presents the means and standard deviation of the maximum walking speed, the sway path, and the isokinetic strength for knee extension. The correlation matrices between the variables are shown in Table 2. The maximum walking speed was significantly related to the time since onset, the sway path and the isokinetic strength of both sides, indicating that standing balance and muscle strength of the lower extremities were determinants of the maximum walking speed. Also there was a significant correlation between the sway path and the isokinetic strength of the both sides, and between the isokinetic strength of the affected and non-affected sides.

The multiple regression analysis, using the maximum walking speed as the dependent variable, and age, height, body weight, time since onset, sway path and isokinetic strength of both sides as the independent variables, indicated :

$$\text{M.W.S.} = 67.41 - 1.21\text{SP} + 0.84\text{A-ISK-S} \quad (R^2 = 0.812)$$

M.W.S., maximum walking speed ; S.P., sway path ; A-ISK-S, isokinetic strength of the affected side.

Step-wise regression analysis revealed that 1) the most significant determinant of maximum walking speed was the isokinetic muscle strength of the affected side with the contribution of 71.9% followed by the sway path, and 2) these two determinants together explained 81.2% of total variance.

Fig. 1 presents the relation of the sway path and the isokinetic strength of the affected side to the maximum walking speed. There is a significant negative correlation between the sway path and the maximum walking speed. We divided arbitrarily the patients into the two groups based on their sway path, using the upper limit of normal value, 30 cm/10 sec (unpublished data) : the stable group

TABLE 2. *Correlation matrices between the variables (n = 29)*

	Age	Sex	Height	Weight	T.S.O.	M.W.S.	S.P.	A-ISK-S	N-ISK-S
Age									
Sex	-0.097								
Height	-0.113	-0.641**							
Weight	-0.298	-0.551**	0.540**						
T.S.O.	-0.141	-0.193	-0.022	-0.066					
M.W.S.	0.003	0.042	0.042	0.253	-0.430*				
S.P.	0.097	0.171	-0.147	-0.316	0.428*	-0.763**			
A-ISK-S	0.042	-0.242	0.189	0.324	-0.386*	0.848**	-0.633**		
N-ISK-S	-0.249	-0.247	0.324	0.327	0.117	0.426*	-0.506**	0.419*	

T.S.O., time since onset ; M.W.S., maximum walking speed ; S.P., sway path.

* $p < 0.05$; ** $p < 0.01$.

Fig. 1. The relation of maximum walking speed to sway path (A) and isokinetic strength of the affected side (B).

with sway path less than the normal value and the unstable one with the sway path more than that. Then, the correlation coefficient between the sway path and the maximum walking speed was not significant in the stable group ($r = 0.321$) and significant in the unstable group ($r = -0.592$, $p < 0.05$).

The relation of the isokinetic strength of the affected side to the maximum walking speed is linear as shown in Fig. 1-B.

Table 3 shows the characteristics of the stable and unstable groups. Mean of age, height, body weight and time since onset did not differ between the two groups. There were significant differences of the maximum walking speed, the sway path and the isokinetic strength of both sides between the stable and unstable groups. Compared to the stable group, the maximum walking speed and the isokinetic strength of both sides were low and the sway path were large in the unstable group. The unstable group were severely disabled in gait due to decreased muscle strength and increased postural sway in station.

Table 4 shows the correlation matrices between the variables in the two groups. The maximum walking speed was related only to the isokinetic strength of affected side in the stable group. On the contrary, the maximum walking speed was related to the sway path and the isokinetic strength of both sides in the unstable group. The relation between the isokinetic strength of both affected and non-affected sides was not significant in the stable group, but significant in the unstable group.

DISCUSSION

The present results indicated that 1) the maximum walking speed of hemiparetic patients was definitely related to the postural stability in station and the muscle strength of affected lower extremity; 2) the patients could be divided into the two groups based on the stability of station: the stable group, their sway

TABLE 3. Demographic variables of the two groups

	Stable (SP < 30), n = 15		Unstable (SP > 30), n = 14	
	Mean	S.D.	Mean	S.D.
Age (years)	57.6	6.5	58.0	9.4
Height (cm)	160.6	7.1	160.2	7.2
Weight (kg)	60.5	7.1	59.2	9.4
T.S.O. (weeks)	14.6	7.6	18.6	5.4
M.W.S. (m/min)	78.4	27.8	25.6	25.2**
Pref. S. (m/min)	44.2	12.1	20.4	10.9**
S.P. (cm/10 sec)	23.0	3.3	43.3	9.1**
A-ISK-S (kg•m)	6.4	3.4	1.7	2.1**
N-ISK-S (kg•m)	11.4	2.6	8.3	4.1*

Pref. S., preferred speed which was calculated by the formula: $Y = 0.45X + 8.9$ (m/min); $\bar{X}$, max. walking speed; $\bar{Y}$, pref. walking speed.

* $p < 0.05$; ** $p < 0.01$.

TABLE 4. Correlation matrices between the variables in the two groups

Unstable group (n = 14)										
	Age	Sex	Height	Weight	T.S.O.	M.W.S.	S.P.	A-ISK-S	N-ISK-S	
Stable group (n = 15)	Age	-0.070	-0.171	-0.331	-0.092	-0.306	0.279	-0.127	-0.329	
	Sex	-0.135	-0.631	-0.407	0.370	-0.277	0.524	-0.189	-0.204	
	Height	-0.037	-0.655**	0.415	0.057	0.394	-0.260	0.468	0.345	
	Weight	-0.237	-0.755**	0.709**	-0.166	0.478	-0.526	0.312	0.269	
	T.S.O.	-0.238	0.095	0.057	0.062	-0.174	0.561*	0.054	-0.034	
	M.W.S.	0.444	-0.157	-0.278	0.061	-0.412	-0.592*	0.562*	0.603*	
	S.P.	-0.361	0.524	-0.234	-0.306	0.144	-0.321	-0.146*	-0.366	
	A-ISK-S	0.257	-0.467	0.092	0.432	-0.390	0.827**	-0.504	0.697**	
	N-ISK-S	0.121	-0.457	0.369	0.433	0.673**	-0.347	-0.081	-0.193	

* $p < 0.05$; ** $p < 0.01$.

path within normal range and the maximum walking speed above 50.6 m/min. (mean - 1 s.d.), and the unstable group, their sway path above the normal range and its maximum walking speed less than 50.8 m/min (mean + 1 s.d.); and 3) the maximum walking speed of the unstable group was related to the sway path and the isokinetic muscle strength of the both sides, whereas that of the stable group only to the isokinetic muscle strength of affected side. Those results confirmed previous studies that walking speed, either maximum or preferred, was related to the postural control in station and the muscle strength of affected side (Dettmann et al. 1987; Mojica et al. 1988; Bohannon 1989).

As for the stability of station, Dettmann et al. (1987), using a force platform which monitored the movement of the center of feet pressure, calculated the area of stability which was defined as a shifted area of the center of feet pressure during the voluntary weight-shifting toward antero-posterior and medio-lateral directions. Mojica et al. (1988) measured the sway path in station using the same apparatus and method in the present study. Bohannon (1989), on the other hand, assessed the standing balance by five-grade ordinal scale. Every report above mentioned showed a significant correlation between the walking speed and the stability of balance. It seems that the measurements of area of stability, sway path, and the clinical rating scale reflect similar disorder of postural control.

The present results showed that there was no correlation between the maximum walking speed and the sway path in the stable group. The maximum walking speed of this group could be higher than 50.6 m/min. According to Yamada et al. (1990), there was a significant correlation between the maximum walking speed and the preferred walking speed in hemiparetic stroke patients ($Y = 0.45X + 8.9$ m/min, $r = 0.929$, $p < 0.01$, X : maximum walking speed, Y : preferred walking speed). Using this equation, we can calculate the preferred speed of the patients. The mean preferred speed of the stable group was 44.2 m/min, and that of the unstable group 20.4 m/min. Dettmann et al. (1987) and Bohannon (1989) reported the mean walking speed of hemiparetic patients in their studies as 28.4 m/min and 20.2 m/min, respectively. Those values were well corresponding to the present result in the unstable group, in which both the stability of station and the isokinetic muscle strength of both sides were main determinants of the maximum walking speed. However, in patients with the maximum walking speed more than 50.6 m/min, the stability of station was not the determinant of maximum walking speed. Moreover, the stability of station was not influenced by the muscle weakness of the affected side in those patients.

As shown in Fig. 1-B, the isokinetic strength for knee extension of the affected side was closely related to the maximum walking speed in both the stable and unstable groups. Moreover, in the unstable group the isokinetic strength of non-affected side was related to the maximum waking speed. Nakamura and Taniguchi (1977) examined the motor time i.e., latency from the initiation of EMG discharge of the prime mover to the onset of mechanical response in reaction

time experiment, of a finger lifting in hemiparetic stroke patients, and reported that there was a correlation between the motor time of the affected and non-affected sides. They attributed prolonged motor time of the non-affected side to the bilateral innervation of pyramidal tract. Similarly, the isokinetic strength of both the affected and non-affected sides were correlated significantly in the unstable group. However, such a relation was not detected in the stable group. Presumably pyramidal lesion of the unstable group was severer than that of the stable group. Another possible reason for the correlation of isokinetic strength between both sides, was the fewer chance of walking in the unstable group. Nakamura et al. (1988), examining the recovery process of walking speed and the isokinetic muscle strength for knee extension in stroke patients after starting gait training, reported that at the start of gait training, the isokinetic muscle strength of the both sides was low and within 4 weeks the strength of the affected side started to increase, but the increase of strength of non-affected side was observed more than 4 weeks after starting the training. They assumed that the fewer chance of walking due to unstable gait at the start of gait training could not recover the disuse atrophy of the non-affected-side, and after 4 weeks patients could walk independently so that the chance of walking increased, then the isokinetic strength increased due to the use of lower extremity. The present results support the notion of the bilateral pyramidal innervation to lower extremities and the disuse atrophy as causes of relation between the maximum walking speed and muscle strength of the both sides. Those phenomena were not observed in the stable group, since they walked well and practiced walking often even during hospital stay, and also the degrees of paresis was not so severe.

Recent researches on the relation of the muscle strength to walking speed are usually examining the strength of the quadriceps muscle as a representative, either isometric or isokinetic. Bohannon and Andrews (1990) showed that the comfortable gait speed correlated positively with the isometric muscle torque of knee extensor muscles ($r = .539$ to $.605$), though the relatively low values as a predictor. In the present study the isokinetic strength of affected side explained 71.9% of total variance in the maximum walking speed. The difference between Bohannon's and the present study could be due to the differences of the measurement of muscle strength and the condition of gait. One reason was due to the measurement of muscle strength. The correlation of isokinetic strength to the maximum walking speed was strong, compared to that of isometric strength (Nakamura et al. 1985). Another reason why the prediction was high in the present study was due to the measurement under the maximum condition. In Bohannon's study the measurement of muscle strength were performed in the condition of patients' maximum effort, but that of walking speed was not. On the contrary, in the present study, the measurements of both the walking speed and the muscle strength were performed under patients' maximum efforts. Generally, performance under the maximum effort shows a representative value, whereas perfor-

mance under preferred condition does not. One reason was due to the measurement of isokinetic strength that is highly correlated to the maximum walking speed compared to the measurement of isometric strength (Nakamura et al. 1985). Another reason why the prediction was high in the present study was due to the measurement under the maximum condition.

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