Ground Reaction Force Patterns in Stroke Patients with Various Degrees of Motor Recovery Determined by Plantar Dynamic Analysis

Chung-Yao Chen[1,3], MD; Paul Wei-Hsien Hong[5], PhD; Chia-Ling Chen[2,3], MD, PhD; Shih Wei Chou[2,3], MD, PhD; Ching-Yi Wu[4], ScD; Pao-Tsai Cheng[2,3], MD; Fuk-Tan Tang[2,3], MD; Hsieh-Ching Chen[6], PhD

Background: To study ground reaction force (GRF) patterns in stroke patients with various degrees of motor recovery, using plantar dynamic analysis.

Methods: Forty-three people with hemiplegic stroke and 20 healthy subjects were enrolled in the study. Motor impairment (motor recovery and muscle tone) and plantar dynamic data (GRF patterns, peak pressure, and walking speeds) were analyzed. GRF patterns were categorized into four patterns based on the force magnitude (spatial features) through time (temporal features) of the vertical GRF. Then stroke patients were classified into good (patterns III and IV) and poor groups (patterns I and II).

Results: Patients with hemiplegic stroke showed characteristic GRF patterns which could be categorized from bimodal (pattern IV) to pathological shapes (I-III). The peak pressures on the paretic side in the metatarsal and toe areas were reduced in stroke patients compared with those in healthy subjects. Walking speeds were higher in the good group than in the poor group ($p < 0.05$). The peak pressures on both sides in the metatarsal and midfoot areas were lower in the poor group than in the good group ($p < 0.05$). GRF patterns were highly correlated with walking speeds ($r = 0.92$, $p < 0.01$). GRF patterns and walking speeds were positively correlated with motor recovery of knee movement ($r > 0.4$, $p < 0.01$), but not with hip and ankle movement or muscle tone in the lower limb.

Conclusions: GRF patterns, correlated with walking speeds, indicate underlying motor control of hemiplegic or hemiparetic gait. Knee motor control may be the most important factor in determining walking performance. Plantar dynamic analysis could allow clinicians an alternative assessment in detecting gait changes and planning therapeutic strategies in stroke patients.

(Chang Gung Med J 2007;30:62-72)

Key words: stroke, plantar pressure, gait, motor, skills, kinetic.

From the [1]Department of Physical Medicine and Rehabilitation, Chang Gung Memorial Hospital, Keelung; [2]Department of Physical Medicine and Rehabilitation, Chang Gung Memorial Hospital, Taipei; [3]Department of Physical Therapy, [4]Department of Occupational Therapy, College of Medicine, Chang Gung University, Taoyuan; [5]School of Sports Medicine, China Medical University, Taichung; [6]Department of Industrial Engineering and Management, Chaoyang University of Technology, Taichung.
Received: Jan. 23, 2006; Accepted: Jun. 27, 2006
Correspondence to: Dr. Chia-Ling Chen, Department of Rehabilitation Medicine, Chang Gung Memorial Hospital. 5, Fushing Street, Gueishan Shiang, Taoyuan, Taiwan 333, R.O.C. Tel.: 886-3-3281200 ext. 3846; Fax: 886-3-3281320; E-mail: clingchen@gmail.com

Many stroke patients regard a faster gait and better gait patterns as the ultimate goals of their rehabilitation.[1,2] The characteristics of gait patterns in hemiplegics depend entirely on primitive patterns.[3] They lack many of the shock-absorbing and energy-conserving mechanisms available to people with normal selective motor control and an accurate afferent system.[3] The loss of motor control and the hypertonic spasticity of the gastrocnemius and soleus stimulated by standing upright and walking results in an equinovarus gait. It also generates an increased lateral plantar support and a reduced push off. Impairment in muscle strength,[4-6] motor and sensory functions,[7-9] spasticity,[6] and balance[5,9-11] have been suggested to be related to the inability of hemiplegic patients to walk in a normal pattern. Many studies have addressed the causes of slow gait in patients with stroke,[4,6,9,10,12] but there is little research on the gait patterns of patients with various degrees of motor recovery.

Both force and temporal-stride analysis can help us understand the underlying mechanism of hemiplegic gait in stroke patients. The analysis of vertical forces during gait provides information on weight bearing. Previous studies have examined gait in stroke patients using many methods, including temporal-stride,[3,8,12] force plate[13-15] and plantar dynamic[16,17] analysis. Plantar dynamic analysis is an easy, convenient, and portable tool for clinicians to investigate foot contact patterns. The magnitude and distribution of forces that pressurize the sole of the foot during walking may reflect its structural and functional status.[16,17] Previous studies have focused on the relationship between the distribution of plantar pressure and the spasticity of the hemiplegic leg.[16,17] Few studies have addressed the relationship between plantar pressure and motor recovery in stroke patients.[18,19] Wong et al.[19] found three ground reaction force (GRF) patterns, which were correlated with walking speed and motor recovery status in the paretic leg, in stroke patients. The motor recovery status of the paretic leg is composed of individual joint control. Hip, knee and ankle joint motor control are especially important. However, which joint plays the most important role in determining the gait patterns remains unknown. This study investigates GRF patterns in stroke patients and their association with the status of motor recovery of the proximal and distal lower limbs using plantar dynamic analysis. First, the GRF patterns of the stroke patients were determined and categorized based on the force magnitude (spatial features) through time (temporal features) using plantar dynamic analysis. Then, the GRF patterns were correlated with walking speed and motor recovery status to understand the hemiplegic gait and the importance of lower limb control in patients with stroke.

METHODS

Subjects

Hemiplegic stroke patients who were in stable condition and could walk without assistance were recruited for this investigation. Patients who met the following entry criteria were included; (1) unilateral hemiplegia caused by cerebral hemisphere stroke; (2) good cooperation and compliance in gait analysis; (3) ability to walk independently for more than 10 m; (4) absence of cerebellar or brain stem strokes; (5) lack of other peripheral or central nervous system dysfunction; (6) absence of active inflammatory or pathologic changes in the joints of the lower limbs, or foot deformities (such as pes valgus, pes cavus, hallux valgus or hallux rigidus) in the previous 6 months; (7) lack of severe visual spatial dysfunction; and (8) no active medical problems. The Hospital Human Research Ethics Committee approved this study. All patients received an explanation of the study and gave informed consent before enrollment. A total of 43 patients (25 men and 18 women), with an average age of 55.5 years (range, 45-76 years), were involved in this study. The pathology of the strokes in these patients were infarction in 30 and hemorrhage in 13 patients (middle cerebral arterial infarction in 22, anterior cerebral infarction in five, lacunar infarction in three, thalamic hemorrhage in four and putaminal hemorrhage in nine). The average duration after stroke onset was 10.3 months. Another 20 healthy subjects (55.9 $\pm$ 10.9 years, 11 men and nine women), without brain lesions, orthopedic disorders or neuromuscular disorders, were selected as the healthy control group for plantar dynamic data comparison.

Apparatus

The Pedar in-shoe pressure measurement system (Novel GmbH, Munich, Germany) (Fig. 1), which has a sampling rate of 50 Hz, was used to record

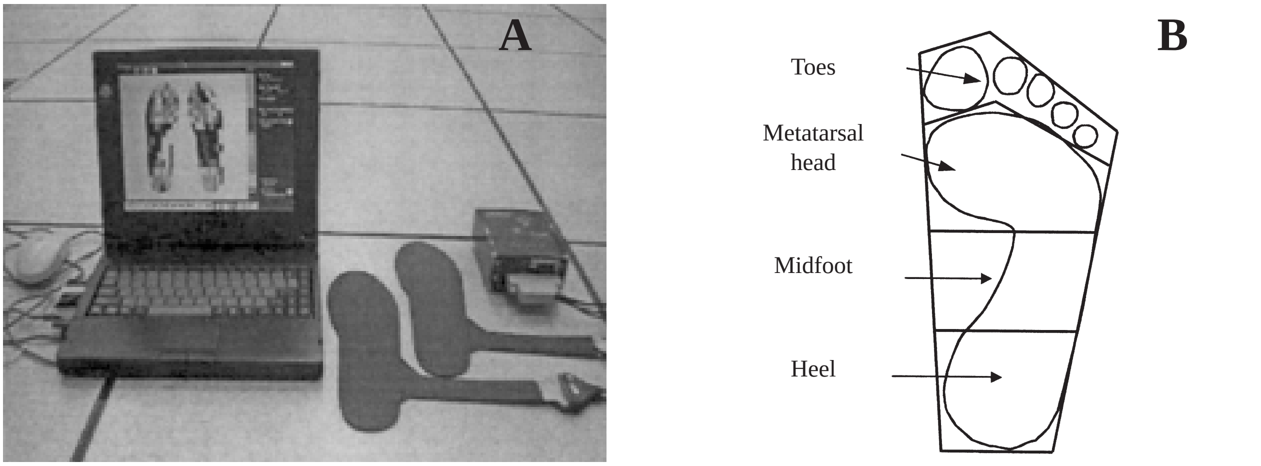

Fig. 1 (A) Pedar in-shoe pressure measurement system. (B) The footprint was divided into four regions: heel, midfoot, metatarsal head, and toes.

pressure and force data. The validity of the capacitance sensor used with the Pedar system has been documented previously.[20] The system consisted of an A/D conversion box which was attached to the participant's waist and a cable connected to a laptop computer for data collection and storage. The capacitance sensor insole was attached to the Pedar system. The insole was approximately 2 mm thick and consisted of a matrix of 90 to 100 capacitance transducers. Before fitting the participants with the equipment, the sensor in each insole was calibrated using calibration software and an air bladder that was inflated to load the insoles to various pressures throughout the measurement range of 0 to 60 N/cm^2. The system was non-invasive, easy to set up, and particularly adapted to hemiplegic gait analysis.

Procedures

All stroke patients underwent motor assessments at the time of plantar dynamic analysis approximately ten months after the stroke occurred. Motor assessments, evaluated by the same experienced physical therapist covered motor recovery and spasticity.

The motor recovery was evaluated using Brunnstrom's method.[21] Brunnstrom's recovery stages were used because they reflect underlying motor control based on the clinical assessment of the quality of movement.[22] Patients were asked to perform voluntary hip/knee/ankle motions while sitting on a straight-backed chair without a front rung. The voluntary movements included hip flexion, knee flexion, ankle dorsiflexion and knee extension. The movements were scored on a five-point rating scale: 0 represented a complete lack of movement and 4 indicated the ability to perform the complete range of motion.[21] The degree of spasticity in the ankle plantar flexors and knee extensors of the affected lower extremity were evaluated using the Modified Ashworth scale (MAS), which was a six-point rating scale.[23]

During the plantar pressure evaluation, all subjects were weighed and requested to wear flat shoes for the test. Inside each shoe, a measured insole was inserted corresponding to the size of the subject's foot. All subjects were instructed to walk along a smooth, horizontal 10 m-long walkway at a comfortable speed. We evaluated only the middle five steps to avoid the variable steps associated with initiation and termination of gait.

Data analysis

NovelWin software programs (Novel GmbH, Munich, Germany) were used to analyze the parameters, including peak plantar pressure, GRF patterns, and walking speeds. We obtained data from the whole foot which was divided into four regions: heel, midfoot, metatarsal head, and toes. For all subjects, these four regions were consistently defined as a percentage of the total foot length of the subject's footprint (Fig. 1). The heel comprised the first 30% of the foot length, the midfoot comprised the next

30%, the metatarsal heads comprised the following 25%, and the toes comprised the remaining 15%. GRF pattern classification was based on the force magnitude (spatial features) through time (temporal features) of the vertical GRF (Fig. 2).[19] The force was represented as a percentage of body weight (% BW) and the time was normalized according to the percentage of the gait cycle (% GC). GRF patterns were classified into four patterns: pattern I with an irregular shape, pattern II with an irregular inverted-V shape, pattern III with an inverted-V or inverted-U shape, and pattern IV with a bimodal M shape.

GRF pattern recognition was analyzed by one author. Twenty reports were selected at random for the reliability test. GRF patterns were analyzed again by the same author one month later for the test-retest reliability analysis. The same GRF pattern reports were also sent to another author for the inter-rater reliability analysis.

Statistical analysis

Statistical analysis was performed using SPSS 10.0 (SPSS Inc, Chicago, Illinois). The stroke patients were classified into good (GRF patterns III and IV) and poor (GRF patterns I and II) groups. The gender and clinical data (associated diseases, surgical condition, type of stroke, side of hemiplegia and sensory function) were compared by chi-square testing. A Mann-Whitney U test was used to analyze the motor recovery and muscle tone among the groups of stroke patients. An independent t-test was performed on some demographic data (age, height, and weight), peak pressure data and walking speeds for the two stroke groups. Spearman correlation coefficients were used to elucidate the relationship between motor impairments (motor recovery, muscle tone) and gait data (GRF patterns and walking speeds). Differences were considered to be significant at the $p < 0.05$ level.

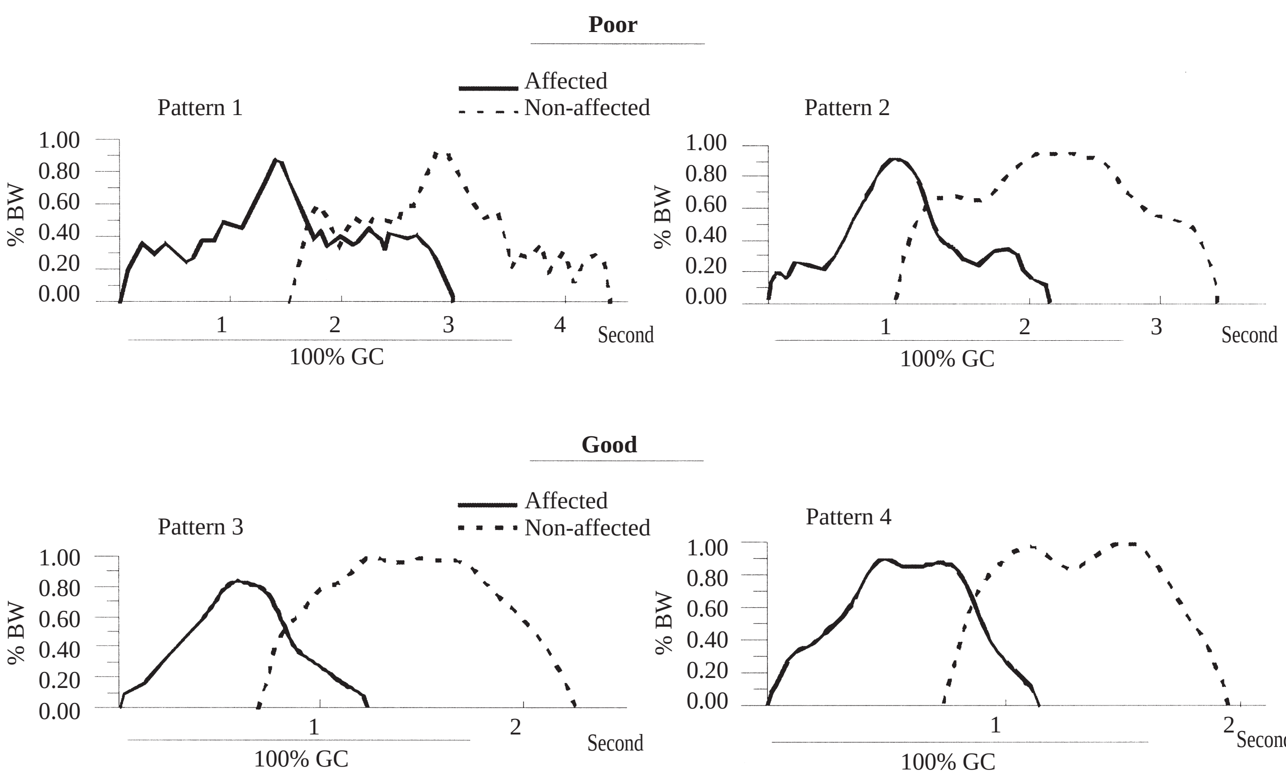

Fig. 2 Ground reaction force (GRF) patterns are classified into four patterns based on the force magnitude (spatial features) through time (temporal features) of the vertical GRF The y-axis represents the vertical ground reaction force expressed as a percentage of body weight (% BW) and the x-axis represents the time sequence expressed as a percentage of the gait cycle (% GC).

RESULTS

Four GRF patterns were identified in stroke patients based on the spatio-temporal features of the applied vertical GRF during walking (Fig. 2). Ten patients had pattern I, 13 had pattern II, 10 had pattern III, and ten had pattern IV. Pattern IV was similar to the GRF pattern of the healthy subjects. The test-retest reliability coefficient (γ) for the GRF patterns was 0.88 ($p < 0.001$), whereas the inter-rater reliability coefficient was 0.85 ($p < 0.001$). These coefficients indicated a high level of stability and reliability.

Eighteen patients had right-side hemiplegia, and the rest had left-side hemiplegia. The good and poor groups of stroke patients did not differ significantly in age or gender. Associated diseases, surgical intervention, type of stroke (infarction vs. hemorrhage), side of hemiplegia (right vs. left) and sensory impairment did not vary significantly between the two groups of stroke patients (Table 1).

Motor impairment

The motor recovery associated with knee flexion, knee extension and ankle dorsiflexion of the good group were better than that of the poor group ($p < 0.05$; Table 2). However, the motor recovery associated with hip flexion did not vary significantly between groups. The muscle tone of the knee extensor and the ankle plantar flexor did not differ significantly between these two groups.

Analysis of plantar dynamics

The walking speeds were reduced in stroke patients compared with the healthy subjects (Table 3). The walking speeds were higher in the good group than in the poor group ($p < 0.05$, Table 3). The peak pressures on the paretic side in the metatarsal and toe areas were reduced in the stroke patients compared with the healthy subjects (Table 3). The peak pressures in the paretic metatarsal areas were greater than the toe areas in the healthy subjects, however, the peak pressures in the paretic metatarsal areas were lower than the toe areas in the stroke patients. The peak pressures on both sides in the metatarsal and midfoot areas were lower in the poor group than in the good group of stroke patients ($p < 0.05$).

Table 1. Data from the Stroke Patients and Healthy Subjects

Data	Stroke groups		Healthy subjects	*p* value
	Poor (n = 23)	Good (n = 20)	(N = 20)	
Demographic data				
Body height (cm)	160.7 ± 8.5	163.2 ± 8.6	163.6 ± 6.5	0.686
Body weight (kg)	59.7 ± 9.9	63.8 ± 11.8	58.9 ± 4.4	0.170
Age (year)	57.3 ± 14.7	54.5 ± 16.5	55.9 ± 10.9	0.534
Foot length (cm)	22.4 ± 1.0	22.3 ± 0.8	23.1 ± 1.1	0.106
Foot width (cm)	7.6 ± 0.5	7.7 ± 0.4	7.8 ± 0.4	0.309
Sex (male)	13 (56%)	12 (60%)	11 (55%)	0.513
Clinical data				
Associated diseases*	16 (70%)	15 (75%)		0.692
Surgery	4 (17%)	4 (20%)		1.000
Type of stroke (infarction)	17 (74%)	13 (65%)	0.526	
Hemiplegic side (right)	11 (48%)	7 (35%)		0.395
Sensory impairment	16 (70%)	13 (65%)		0.750

Values are expressed as mean ± SD, or n (%).
Associated diseases*: diabetes, hypertension, and coronary artery disease

Table 2. Motor Impairment in the Two Stroke Groups

Motor functions	Stroke groups Poor (n = 23)	Good (n = 20)	Mann-whitney U *p* value
Motor recovery*			
Hip flexion			0.134
Weak (0-2)	18 (78.3%)	12 (60.0%)	
Strong (3-4)	5 (21.7%)	8 (40.0%)	
Knee flexion			< 0.001
Weak (0-2)	22 (95.7%)	11 (55.0%)	
Strong (3-4)	1 (4.3%)	9 (45.0%)	
Knee extension			0.004
Weak (0-2)	13 (56.5%)	5 (25.0%)	
Strong (3-4)	10 (43.5%)	15 (75.0%)	
Ankle dorsiflexion			0.021
Weak (0-2)	23 (100.0%)	14 (70.0%)	
Strong (3-4)	0 (0.0%)	6 (30.0%)	
Muscle tone†			
Knee extensor			0.887
Mild (0-1+)	13 (56.5%)	12 (60.0%)	
Severe (2-3)	10 (43.5%)	8 (40.0%)	
Ankle plantar flexor			0.528
Mild (0-1+)	16 (69.6%)	14 (70.0%)	
Severe (2-3)	7 (30.4%)	6 (30.0%)	

Data was expressed as n (%).
* Brunnstrom's recovery stage
† Modified ashworth scale

Correlations between motor impairment and plantar dynamics

GRF patterns were positively correlated with motor recovery of knee flexion and knee extension ($r > 0.4$, $p < 0.01$; Table 4). However, GRF patterns were not correlated with the motor recovery of hip

Table 4. Correlations among Ground Reaction Force (GRF) Patterns, Walking Velocity and Motor Impairments in Stroke Patients

Variables	GRF patterns	Walking velocity
GRF patterns		0.924*
Motor recovery†		
Hip flexion	0.292	0.293
Knee flexion	0.607*	0.424*
Knee extension	0.423*	0.455*
Ankle dorsiflexion	0.280	0.102
Muscle tone‡		
Knee	–0.152	–0.298
Ankle	–0.030	–0.197

* $p < 0.01$, Spearman correlation coefficients.
Significance is indicated if r > 0.304 at the alpha level = 0.05 of significance and degree of freedom = 41.
† Brunnstrom's recovery stage
‡ Modified ashworth scale

Table 3. Walking Velocity and Peak Pressures in the Four Regions in the Stroke Patients and Healthy Subjects

Parameters	Stroke groups Poor (n = 23)	Good (n = 20)	t-test *p* value	Healthy (N = 20)
Velocity (% BH/sec)				
Non-paretic	12.4 ± 3.4	22.6 ± 5.8	< 0.001	51.5 ± 8.5
Paretic	10.5 ± 3.0	20.0 ± 6.3	< 0.001	
Peak pressures				
Heel (N/cm²)				
Non-paretic	19.7 ± 5.8	22.2 ± 4.6	0.123	19.6 ± 2.4
Paretic	15.6 ± 5.5	16.6 ± 4.7	0.643	
Midfoot (N/cm²)				
Non-paretic	8.0 ± 3.8	10.6 ± 3.3	0.038	7.6 ± 2.1
Paretic	6.5 ± 2.6	10.4 ± 2.8	< 0.001	
Metatarsal (N/cm²)				
Non-paretic	12.4 ± 3.8	17.6 ± 4.6	< 0.001	24.8 ± 5.0
Paretic	10.5 ± 3.2	12.6 ± 3.2	0.038	
Toes (N/cm²)				
Non-paretic	20.2 ± 8.8	19.6 ± 8.2	0.814	19.5 ± 5.0
Paretic	14.6 ± 5.4	13.3 ± 3.9	0.359	

Abbreviation: BH: body height.
Data are expressed as mean ± SD.

flexion or ankle dorsiflexion, or the muscle tone in the lower limb. GRF patterns were highly correlated with the walking speeds ($r = 0.92$, $p < 0.01$; Table 4; Fig. 3). Walking speeds were also positively correlated with motor recovery of knee flexion and knee extension ($r > 0.4$, $p < 0.01$; Table 4, Fig. 3), but not with motor recovery of hip flexion or ankle dorsiflexion, or the muscle tone in the lower limbs.

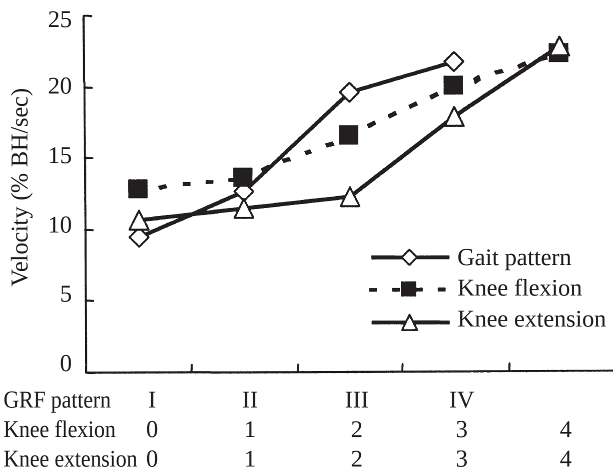

Fig. 3 Relationships between the walking speeds, and ground reaction force (GRF) patterns and motor recovery in stroke patients. The velocity is normalized according to percentage of body height (% BH).

DISCUSSION

GRF patterns, correlated with walking speeds and motor recovery in stroke patients in this study, indicate underlying motor control of hemiplegic or hemiparetic gait. Walking speed is an effective index of the abnormality of gait, overall functional status, and clinical progress.[24,25] The GRF patterns identified herein in stroke patients who walked independently were similar to those of stroke patients with hemiplegia.[19,26] GRF patterns had high reliability and good validity. Their validity was shown by a high correlation with motor recovery and walking speeds. Patients with pattern IV have good motor control associated with grading forces ("M"-shaped vertical forces) in the heel-strike, mid-stance and push-off phases, similar to that in normal subjects.[27] Patients with pattern III have fair motor control, associated with a poor capacity to roll over the affected foot because of emerging forces (inverted "V"- or "U"-shaped forces pattern) in the heel-strike, mid-stance and push-off phases. Patients with patterns I and II have poor motor control with poor stability, resulting in the application of irregular forces. Furthermore, patients with pattern I may need supervised ambulation due to unstable gait, especially when walking on uneven ground or when walking long distances.

GRF patterns, revealed by plantar dynamics, could provide clinicians an alternative, easy assessment tool to detect subtle gait changes in patients with different motor statuses after hemiplegic stroke. A normal GRF pattern is comprised of the sequences of the heel-strike, mid-stance, and push-off phases. There is a loading response to absorb the vertical shock during the heel-strike phase and a propulsive force during the push-off phase. Therefore, a normal GRF pattern is a bimodal shape because the vertical forces applied during the heel-strike and push-off phases exceed body weight, while those applied during the mid-stance phase are less than body weight.[27] Patients with hemiplegic stroke may lose the heel-strike and push-off mechanism, altering the GRF pattern from bimodal (pattern IV) to pathological shapes (I-III). Stroke patients with patterns III and IV exhibited better isolated lower limb movement, and could walk with patterns that were closer to normal. Those with patterns I and II exhibited synergistic and mass movements, and walked with a synergistic gait. Titianova et al.[28] revealed that the variables of the hemiparetic gait changed in a stereotyped manner, perhaps because of the preserved central pattern generators in the spinal cord, which may function in a stereotyped fashion under residual supraspinal motor control, attempting to retain the basic structure of the gait and preserve as much of the central programming as possible.[29]

Motor control of knee movement may be important in determining GRF patterns and walking speed. Using correlation analysis we found that GRF patterns and walking velocities were correlated with motor recovery of knee movement, but not with hip and ankle movement. Some studies also found proximal lower limb control may be the main determinant of walking speed.[8,30-32] Some studies showed knee movement was an important factor in determining the gait pattern of stroke patients.[33-35] This is reflect-ed by a hemiplegic gait with reduced knee flexion at toe-off and mid-swing in the paretic limb.[35] Furthermore, this study found that the degree of spasticity of the affected ankle plantar flexors and knee extensors was not related to the walking velocity in patients with stroke, which is compatible with previous studies.[5,6,9,12,36] Further serial follow up studies with the same patient group are needed to clarify the relationship between motor control and gait performance.

Our findings of decreased peak pressure over the paretic metatarsal and toe areas suggest stroke patients walk with limited rolling-over and insufficient push-off, which is consistent with earlier studies.[18,28,32] Titianova et al.[28] also posited that the peak pressure in the metatarsal area was reduced in hemiplegic patients. In this study, stroke patients walked with insufficient push-off and relied on the toe areas to help push-off. The peak pressures in the paretic toe areas were greater than in the metatarsal areas in patients with stroke, although the peak pressures in the metatarsal areas were greater than in the toe areas in the healthy subjects. Moreover, the peak pressures in both the paretic and nonparetic legs in the metatarsal and midfoot areas were significantly lower in the poor group than in the good group. This indicates the stroke patients with GRF patterns III and IV have better weight-shifting ability during the gait cycle, not only in the paretic leg but also in the non-paretic leg, than those with GRF patterns I and II. The reasons may be the varieties in the non-paretic limb involvement or compensatory adaptations among stroke patients with different motor recovery statuses. Previous studies suggested severe cerebral infarction results in primary motor control problems in both lower limbs although, obviously, they are more pronounced on the side of hemiplegia.[37,38] The non-paretic limb adaptations may be the result of complex compensatory mechanisms, or a real sensorimotor perturbation, which would cause stroke patients to adapt their walking strategy.[18,32]

The results concerning walking speed and GRF patterns herein can be used to plan therapeutic strategies for stroke patients independently. Many therapeutic strategies have been applied in stroke patients with hemiplegic gait, such as weight-bearing training, strengthening and facilitation techniques, sometimes with the assistance of orthoses or walking aids.[39] However, planning therapeutic strategies should be tailored to the patient's individual problems. GRF patterns may provide a choice of appropriate therapeutic strategies. For example, patients with GRF pattern IV (faster walking) may require weight-bearing training to increase the forces applied to the affected limb. Patients with GRF pattern III may need graded force training during the heel-strike, mid-stance and push-off phases, as well as weight-bearing training due to poor roll over capacity with reduced force. Patients with GRF patterns I and II (slower walking) may have to undergo strengthening or facilitation techniques to improve the motor control of the affected limb, especially knee movement, or may require bracing, such as ankle foot orthoses, to improve stability. They may also need weight-bearing training and supervised ambulation training or training using a walking aid to increase the stability and safety of walking.

The GRF patterns, correlated with walking speeds and motor recovery of stroke patients herein, reveal underlying motor control of hemiplegic or hemiparetic gait. Patients with hemiplegic stroke may lose the heel-strike and push-off mechanisms, altering the GRF pattern from bimodal (pattern IV) to pathological shapes (I-III). Stroke patients walk with insufficient push-off and rely on the toe areas to help push-off. Therefore, quantitative plantar dynamic data can be used to evaluate walking performance, to measure improvement, and to plan therapeutic strategies in patients with stroke. Future studies are needed to clarify the relationships between therapeutic strategies and gait patterns in patients with stroke.

Acknowledgement

The authors would like to thank the National Science Council of Taiwan for financially supporting this research under Contract No. NSC93-2314-B-182A-045.

REFERENCES

1. Bohannon RW, Andrews AA, Smith MB. Rehabilitation goals of patients with hemiplegia. Int J Rehabil Res 1988;11:181-3.
2. Bohannon RW, Horton MG, Wikholm JB. Importance of four variables of walking to patients with stroke. Int J Rehabil Res 1991;14:246-50.
3. Mizrahi J, Susak Z, Heller L, Najenson T. Variation of time-distance parameters of the stride as related to clinical gait improvement in hemiplegics. Scand J Rehabil Med

1982;14:133-40.
4. Nakamura R, Hosokawa T, Tsuji I. Relationship of muscle strength for knee extension to walking capacity in patients with spastic hemiparesis. Tohoku J Exp Med 1985;145:335-40.
5. Bohannon RW. Gait performance of hemiparetic stroke patients: selected variables. Arch Phys Med Rehabil 1987;68:777-81.
6. Bohannon RW, Andrews AW. Correlation of knee extensor muscle torque and spasticity with gait speed in patients with stroke. Arch Phys Med Rehabil 1990;71:330-3.
7. De Quervain IA, Simon SR, Leurgans S, Pease WS, McAllister D. Gait pattern in the early recovery period after stroke. J Bone Joint Surg Am 1996;78:1506-14.
8. Brandstater ME, de Bruin H, Gowland C, Clark BM. Hemiplegic gait: analysis of temporal variables. Arch Phys Med Rehabil 1983;64:583-7.
9. Nadeau S, Arsenault AB, Gravel D, Bourbonnais D. Analysis of the clinical factors determining natural and maximal gait speeds in adults with a stroke. Am J Phys Med Rehabil 1999;78:123-30.
10. Suzuki K, Imada G, Iwaya T, Handa T, Kurogo H. Determinants and predictors of the maximum walking speed during computer-assisted gait training in hemiparetic stroke patients. Arch Phys Med Rehabil 1999;80:179-82.
11. Dettmann MA, Linder MT, Sepic SB. Relationships among walking performance, postural stability, and functional assessments of the hemiplegic patient. Am J Phys Med 1987;66:77-90.
12. Hsu AL, Tang PF, Jan MH. Analysis of impairments influencing gait velocity and asymmetry of hemiplegic patients after mild to moderate stroke. Arch Phys Med Rehabil 2003;84:1185-93.
13. Griffin MP, Olney SJ, McBride ID. Role of symmetry in gait performance of stroke with hemiplegia. Gait Posture 1995;3:132-42.
14. Kim CM, Eng JJ. Symmetry in vertical ground reaction force is accompanied by symmetry in temporal but not distance variables of gait in persons with stroke. Gait Posture 2003;18:23-8.
15. Carlsoo S, Dahlof AG, Holm J. Kinetic analysis of the gait in patients with hemiparesis and in patients with intermittent claudication. Scand J Rehabil Med 1974;6:166-79.
16. Meyring S, Diehl RR, Milani TL. Dynamic plantar pressure distribution measurements in hemiparetic patients. Clin Biomech 1997;12:60-5.
17. Femery V, Moretto P, Renaut H, Thevenon A, Lensel G. Measurement of plantar pressure distribution in hemiplegic children: changes to adaptative gait patterns in accordance with deficiency. Clin Biomech 2002;17:406-13.
18. Gaviria M, D'Angeli M, Chavet P. Plantar dynamics of hemiplegic gait: a methodological approach. Gait Posture 1997;4:297-305.
19. Wong AM, Pei YC, Hong WH, Chung CY, Lau YC, Chen CP. Foot contact pattern analysis in hemiplegic stroke patients: an implication for neurologic status determination. Arch Phys Med Rehabil 2004;85:1625-30.
20. Boyd LA, Bontrager EL, Mulroy SJ, Perry J. The reliability and validity of the Novel Pedar system of in-shoe pressure measurement during free ambulation. Gait Posture 1997;5:165.
21. Sawner, KA, LaVigne, JM. Brunnstrom's movement therapy in hemiplegia: a neurophysiologial approach. 2nd ed. Philadelphia: JB Lippincott Company, 1992:64-5.
22. Chen CL, Wong AMK, Chen HC, Cheng PT, Tang FT. Correlation of polyelectromyographic patterns and clinical upper motor neuron syndrome in hemiplegic stroke patients. Arch Phys Med Rehabil 2000;81:869-75.
23. Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. Phys Ther 1987;67:206-7.
24. Wagenaar RC, Beek WJ. Hemiplegic gait: a kinematic analysis using walking speed as a basis. J Biomech 1992;25:1007-15.
25. Murray MP, Mollinger LA, Gardner GM, Sepic SB. Kinematic and EMG patterns during slow, free, and fast walking. J Orthop Res 1984;2:272-80.
26. Chen CL, Chen HC, Wong MK, Tang FT, Chen RS. Temporal stride and force analysis of cane-assisted gait in people with hemiplegic stroke. Arch Phys Med Rehabil 2001;82:43-8.
27. Murray MP, Seireg AH, Scholtz RC. A survey of the time, magnitude and orientation of forces applied to walking sticks by disabled men. Am J Phys Med 1969;48:1-13.
28. Titianova EB, Pitkanen K, Paakkonen A, Sivenius J, Tarkka IM. Gait characteristics and functional ambulation profile in patients with chronic unilateral stroke. Am J Phys Med Rehabil 2003;82:778-86.
29. Dimitrijevic MR. Gerasimenko Y. Pinter MM. Evidence for a spinal central pattern generator in humans. Ann NY Acad Sci 1998;860:360-76.
30. Wade DT, Wood VA, Heller A, Maggs J, Langton HR. Walking after stroke. Measurement and recovery over the first 3 months. Scand J Rehabil Med 1987;19:25-30.
31. Friedman PJ. Gait recovery after hemiplegic stroke. Int Disabil Stud 1990;12:119-22.
32. Chen CL, Chen HC, Tang FT, Wu CY, Cheng PT, Hong WH. Gait performance with compensatory adaptations in stroke patients with different degrees of motor recovery. Am J Phys Med Rehabil 2003;82:925-35.
33. Pease WS, Quesada PM. Kinematics and kinetics of gait. In: Braddom RL, eds. Physical medicine & rehabilitation. 1st ed. Philadelphia: W.B. Saunders Co., 1996:97.
34. Mulroy S, Gronley JA, Weiss W. Use of cluster analysis for gait pattern classification of patients in the early and late recovery phases following stroke. Gait Posture

2003;18:114-25.
35. Chen C, Patten C, Kothari DH. Gait differences between individuals with post-stroke hemiparesis and non-disabled controls at matched speeds. Gait Posture 2005;22:51-6.
36. Norton BJ, Bomze HA, Sahrmann SA, Eliasson SG. Correlation between gait speed and spasticity at the knee. Phys Ther 1975;55:355-9.
37. Shiavi R, Bugle HJ, Limbird T. Electromyographic gait assessment, Part 2: preliminary assessment hemiparetic synergy patterns. J Rehabil Res Dev 1987;24:24-30.
38. Wagenaar R, Beek W. Hemiplegic gait: a kinematic analysis using walking speed as a basis. J Biomech 1992;25:1007-15.
39. Carr JH, Shepherd RB. Stroke rehabilitation-guidelines for exercise and training to optimize motor skill. 1st ed. Edinburgh: Butterworth-Heinemann, 2003:111-249.

不同運動控制能力之中風病人之地面作用力特性研究

陳仲堯[1,3] 洪維憲[5] 陳嘉玲[2,3] 周適偉[2,3] 吳菁宜[4] 鄭寶叙[2,3] 鄧復旦[2,3] 陳協慶[6]

背 景： 研究不同運動控制能力之中風病人之地面作用力 (ground reaction force) 特性。

方 法： 本實驗收集 43 位中風病人以及 20 位健康之對照組。主要的評估項目包括病患本身的運動功能障礙 (包括下肢肌肉張力及下肢運動功能恢復程度) 以及足底動力學的變化 (包括地面作用力型態，足底壓力以及步行速度)。根據地面作用力型態的特徵我們嘗試將其歸類成四組，然後中風病人再根據其不同的地面作用力型態的組別分成較佳及較差兩組。

結 果： 中風病人行走的地面作用力型態相當具有特性，因此可以加以分成爲四類。在中風患側最大足底壓力 (peak pressure) 方面，其在蹠骨區 (metatarsal) 以及腳指區的壓力較正常人低。在步行速度方面，較佳組明顯的較較差組還要來得快 ($p < 0.05$)。在足底最大壓力方面，較佳組在雙腳蹠骨區和中足 (midfoot) 位置明顯的較較差組還要大 ($p < 0.05$)。地面作用力型態和步行速度呈現高度的正相關 ($r = 0.92$, $p < 0.001$)。地面作用力型態和步行速度均和膝關節的運動控制呈現正相關 ($r > 0.4$, $p < 0.01$)，但是和髖關節以及踝關節的運動控制無關，也和下肢的肌肉張力無關。

結 論： 由地面作用力型態和步行速度的高度相關，可以推論地面作用力型態反映了中風病人步態的特性。膝關節的運動控制能力在中風病人的步態表現方面佔有重要的地位。足底動力學的分析是另一種研究中風步態變化的方法，並且可以提供治療上的參考。

(長庚醫誌 2007;30:62-72)

關鍵詞： 中風，足底壓力，步態，運動，技能，動力學。

長庚紀念醫院 [1]基隆院區 復健科；[2]台北院區 復健科；長庚大學 [3]物理治療學系，[4]職能治療學系；[5]中國醫學大學 運動醫學所；[6]朝陽科技大學 工業工程與管理系

受文日期：民國95年1月23日；接受刊載：民國95年6月27日

通訊作者：陳嘉玲醫師，長庚紀念醫院 復健科。桃園縣333龜山鄉復興街5號。Tel.: (03)3281200 ext 3846; Fax: (03)3281320; E-mail: clingchen@gmil.com