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KINEMATIC AND KINETIC ASYMMETRIES IN HEMIPLEGIC PATIENTS' GAIT INITIATION PATTERNS

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Objective: **To assess the kinetic and kinematic characteristics of hemiplegic stroke patients' gait initiation patterns during the various gait initiation phases.**
Design and subjects: **Gait initiation was studied in 3 hemiplegic subjects with a spastic equinus varus foot and 3 control subjects.**
Methods: **Temporal and kinetic analysis of gait initiation was performed with 2 AMTI® force plates, and kinematic analysis of gait initiation with an ELITE® optoelectronic system. A one-way ANOVA was performed directly on the phase durations, forces, centre of pressure displacements, stride length, and ankle motion range.**
Results: **Duration of the monopodal phase was shorter in hemiplegic patients when the affected leg rather than the sound one was used as the supporting leg. Propulsion forces were exerted by the hemiplegic patients' sound leg during the postural phase. Hemiplegic patients' body weight was supported more by the sound leg than by the affected leg. Knee was lifted higher on the affected side during the swing phase to compensate for the equinus. Initial contact was performed with a flat foot on the affected side.**
Conclusion: **Quantitative data obtained on the gait initiation phase suggest that hemiplegic patients develop asymmetrical adaptive posturo-motor strategies to compensate for their impairments.**

Key words: hemiplegic, equinus varus foot, gait initiation, kinetic, kinematic.

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INTRODUCTION

Stroke is a frequent pathological event, resulting in impairments such as reduced analytical motor command, spasticity, reduced range of joint motion and decreased sensitivity, which can lead in turn to disabilities, especially as far as walking is concerned.

Previous studies have been carried out on patients after stroke using movement analysis systems. Pelissier et al. (1) observed the following changes in hemiplegic patients' walking patterns: a decrease in the propulsion on the hemiplegic side, a decrease in the duration of the stance phase on the hemiplegic side, a decrease in the step length when the hemiplegic side is the supporting side, and a decrease in the walking speed. Stroke patients' postural balance is also impaired, as described by Perennou et al. (2). In the latter study, the weight-bearing was greater on the sound side in hemiplegic patients, and the subjective vertical was modified in patients after stroke (3). Patients first had to recover postural balance for gait recovery to be possible (4).

These studies have shown that, in patients after stroke, both gait patterns and postural strategies differ significantly from those of able-bodied subjects. However, none of these studies have dealt with the co-ordination between posture and movement, and one of the most suitable ways of studying this co-ordination is to assess gait initiation, because gait initiation is a necessary transitional phase between bipedal stance and on-going gait. The kinematic and kinetic patterns identified so far in normal subjects in gait initiation studies have been found to be altered in patients with central nervous and musculoskeletal lesions, such as Parkinson's disease and knee arthritis, in whom changes in the posturo-motor strategies used have been observed (5).

Studies in which the kinetic, kinematic and electromyographic (EMG) data have been recorded during single leg flexion (6) and gait initiation (7–12) have thrown light on the co-ordination between posture and movement during these tasks. Gait initiation has been found to be a complex biomechanical task involving specific co-ordinated control processes between equilibrium and movement. It is generally recognized (13, 14) that gait initiation starts with a postural phase followed by a monopodal phase, and ends up with a double support phase (Fig. 1a).

As observed in studies by Mann et al. (10) and Brenière et al. (7, 13), the postural phase starts with a backward shift of the centre of pressure (CoP) toward the leg about to be moved, reflecting the forward, lateral angular acceleration of the centre of gravity (CoG) (9, 13–16). Horizontal ground reaction forces are therefore directed forward in the sagittal plane. The initial shift of the CoP results from the activation

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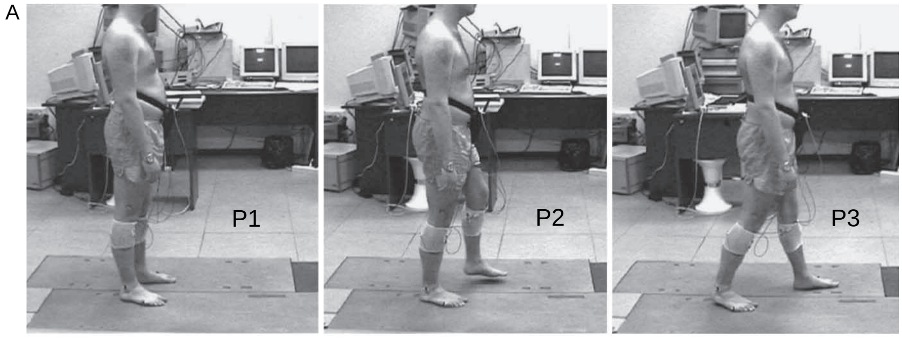

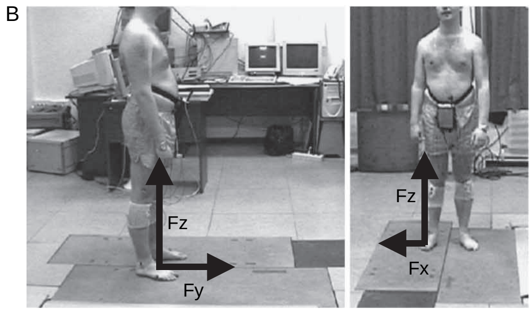

Fig. 1. (A) The 3 gait initiation phases: phase P1 (postural phase), P2 (monopodal phase) and P3 (double support phase). (B) Components of ground reaction force: Fx; the medio-lateral component of the ground reaction force in the horizontal plane, Fy; the antero-posterior component of the ground reaction force in the horizontal plane and Fz; the vertical component of the ground reaction force.

of the tibialis anterior muscles and the inhibition of the triceps surae muscles (17). Likewise, the anterio-posterior horizontal ground reaction forces induce a forward linear acceleration of the CoG (15, 16). As a result, the CoG moves forward toward the stance leg (9, 13). The leading leg is therefore unloaded and becomes free to move.

Gait velocity and step length depend on the propulsive forces generated prior to heel-off (13). By contrast, the duration of gait initiation depends mainly on the subject's mass and inertial properties and on the position of the CoG in relation to the ground, in keeping with the inverted pendulum model (13).

Since the CoP shift occurs prior to the first displacement of the leading leg, the postural phase cannot be identified or quantified simply by performing a clinical examination. After the initial postural phase, the second phase starts with the movement of the leading limb, when the foot leaves the ground. This is a monopodal phase, which can be identified but not quantified by performing a clinical examination. The first step ends with the double support phase. It is necessary to use a movement analysis system and force plates to identify the first (postural) and last (double support) phase, and to quantify the duration of each of the 3 phases.

Little attention has been paid so far to gait initiation in hemiplegic patients after stroke (18–20). The few studies available have focused on the kinetic and EMG gait initiation parameters in hemiplegic patients. The results of these studies showed that the propulsion forces were reduced and the monopodal phase shortened on the affected side, and that the step length and gait velocity values were lower than in the control subjects. Changes in the EMG activities of the hip abductor and adductor muscles were also observed (20).

However, the assessments made in these studies did not include kinematic parameters, such as the range of ankle motion, the location of the initial foot contact, or the ground clearance during the gait initiation phases in hemiplegic patients after stroke. Nor have the links between the changes in the kinetic and kinematic parameters been studied so far in hemiplegic patients.

The aim of the present study was therefore to assess the kinetic and kinematic characteristics of gait initiation during the various gait initiation phases in hemiplegic patients after stroke. These data should help us to understand the effects of central nervous and musculoskeletal lesions on gait initiation and the adaptive strategies used by patients with these lesions.

MATERIAL AND METHODS

Design and subjects

The present study was carried out on hemiplegic patients scheduled for functional equinus varus foot surgery. Three hemiplegic patients after stroke were compared with 3 healthy subjects. There were only 3 subjects because functional surgery of this kind is fairly rare, and we wanted to have a homogenous group of subjects about to undergo this procedure. Characteristic data on the 3 control subjects and the 3 hemiplegic subjects are given in Table I. The control and hemiplegic subjects were matched in terms of age, height, weight and sex.

The patients included in this study had an equinus varus foot impairing standing position and/or gait. They were able to initiate gait by themselves with both the affected and non-affected limb without a cane and were able to understand instructions. No patients with any additional orthopaedic or neurological deficits affecting standing posture or gait were included in the study.

Material

The kinematic study was carried out using an ELITE® optoelectronic system (BTS spa, Milano, Italy) with 6 cameras. The sampling rate was 100 Hz. The displacements of the markers were recorded by 6 infrared

Table I. *Characteristic data for the hemiplegic and control subjects*

	Controls			Hemiplegic patients		
	C1	C2	C3	H1	H2	H3
Sex	F	F	M	F	F	M
Age (years)	55	34	20	55	35	21
Weight (kg)	62.2	53	63.6	64.9	50.9	67
Height (cm)	159	164	180	160	155	167
Time since stroke (years)				4	11	8
Type of stroke				Ischaemia	Haemorrhage	Haemorrhage
Region				Left Sylvian	Right Caps. lent.	Left Thalamus
Hemiplegic side				Right	Left	Right
Ankle Flexion						
KE				$-15°$	$-15°$	$0°$
KF				$-5°$	$-10°$	$+10°$
Spasticity (Ashworth)						
Gastrocnemius				4	3	4
Soleus				3	3	3
Motor command						
TA				Effective	Effective	Effective
TP				Effective	Effective	Ineffective
Fibularis				Ineffective	Effective	Ineffective
Sensory deficits				None	Superficial	Superficial/proprioceptive
Walking distance (km)				>1	>1	>1
Fitting				OS + Crutch	None	Ankle foot orthoses
SSWS m/s	0.91	1.5	1.66	0.43	0.9	1.5
FIM				119/126	124/126	124/126
Barthel index				95/100	100/100	95/100
FAC				5/6	5/6	5/6
Bells test				Successful	Successful	Successful

SSWS = Self-Selected Walking Speed; FIM = Functional Independence Measure; FAC = Functional Ambulation Category; OS = orthopaedic shoes; KE=Knee Extended; KF=Knee Flexed; TA=Tibial Anterior; TP=Tibial Posterior, Caps. lent.=Capsulo-lenticular.

cameras placed both behind and in front of the subject. Six light-reflecting markers were placed on anatomical landmarks: bilaterally, on the lateral femoral condyles, the fibular malleoli and the fifth metatarsal heads.

The kinetic parameters were recorded via 2 AMTI® force-plates (Advanced Mechanical Technology Inc, Watertown MA, USA) 1.5 × 0.46 metres in length, equipped with strain guages, both mounted in the floor side by side. The sampling rate was 500 Hz.

Kinetic and kinematic data were simultaneously recorded and synchronized. The data recorded at each trial were displayed on a personal computer monitor.

Procedure

All patients first underwent a clinical examination, followed by a gait initiation assessment with the same specialist in physical and rehabilitation medicine. The subject was placed barefoot in a standing position, with one foot on each of the AMTI® force plates. The subject began walking at whatever speed he chose when instructed to do so by the operator. The foot to be used to initiate walking was chosen at random and specified by the operator by raising his left or right hand. Each subject performed 10 trials with each lower limb (20 trials/subjects). The first leg to be moved was called the moving leg and the other leg, the supporting leg. All trials in which the moving leg landed on the same force-plate were analysed.

Data analysis

Clinical assessment. The subjects' complaints, the history of the disease, details of the brain lesion and the different treatments previously used to reduce the spasticity were recorded. The impairment levels were also assessed as follows: neurological impairment, orthopaedic impairment (21), spasticity on the modified Ashworth scale (22), motor command, and hemi-neglect with the Bells test (23). Disability levels were assessed as follows: qualitative gait assessment, the comfortable self-selected speed (24) over a distance of 10 metres, the FIM™ (25), the Barthel index (26) and the Functional Ambulation Categories rating (27). The patients' clinical data are summarized in Table I.

Temporal data analysis. The duration of the various gait initiation phases, namely the postural phase (P1), the monopodal phase (P2), the double support phase (P3), as well at the total movement duration, were recorded. The 3 gait initiation phases (Fig. 1a) were defined and measured in the present study on the basis of kinetic parameters, as follows: the P1 was taken to start at time T1, corresponding to the onset of the peak in Fx (Fig. 1b) (the medio-lateral component of the ground reaction force on the horizontal plane) occurring when the weight transfer phase started when the medio-lateral force component recorded on the first force plate changed by at least 5 N for at least 50 milliseconds (ms) (19). P1 ended at time T2, corresponding to the end of the leg movement recording on the force-plate. The P2 was taken to start at time T2 (at the end of the leg movement recording on the force-plate) and to end at time T3, corresponding to the re-contact of the moving leg on the force plate. The P3 was taken to start at time T3 (corresponding to the first contact made by the foot of the moving leg with the force plate) and to end at time T4 with the take-off of the supporting leg when no signal was recorded on the other force-plate (Fig. 2). The total duration of gait initiation was measured from T1 to T4. The ratios between the durations of the various phases and the total movement duration (i.e. the percentage of the total duration) were calculated in order to normalize the values and to make comparisons between subjects. All ASCII data were transferred to Excel® and calculations were carried out with Excel®.

Kinetic data analysis. The area under the curve of Fy (Fig. 3) (the antero-posterior component of the ground reaction forces in the horizontal plane) was measured during the P1, P2 and P3. These values were measured in each lower limb and the total force exerted by the 2 lower limbs during P1 was calculated. These values reflected the force exerted during a given time and were expressed in Newton seconds. If the value was positive, the force was propulsive. If the value was negative, the force was retropulsive. Fy is an accurate index to the propulsive forces responsible for the linear acceleration of the centre of gravity in the sagittal plane (16).

The percentage distribution of the body weight to each lower limb was determined before the beginning of gait initiation (before T1).

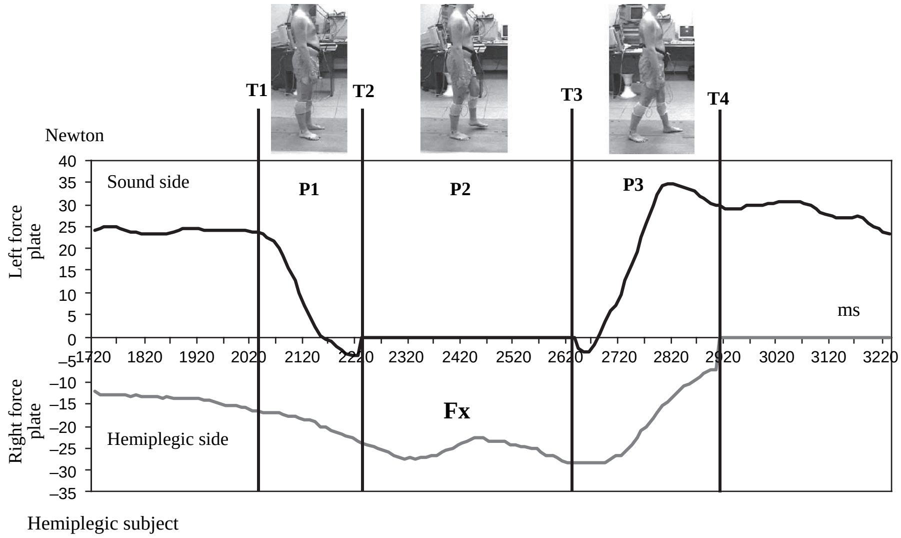

Fig. 2. Determination of the 3 gait intiation phases using Fx (the medio-lateral component of the ground reaction force in the horizontal plane) curve. The 3 phases P1, P2 and P3 were defined in the present study on the basis of kinetic parameters, as follows: the postural phase (PI) started at time Tl corresponding to the onset of the peak in Fx (left force plate), which corresponds to the start of the weight transfer phase, and ended at time T2, corresponding to the end of the force plate recording of the moving leg (left force plate); the monopodal phase (P2) started at time T2 and ended at time T3, corresponding to the initial contact of the moving leg, when the force plate recording started up again (left force plate); the double-support phase (P3) started at time T3 and ended at time T4 with the take-off of the supporting leg, when no further signals were recorded on the other force-plate (right force plate).

The peak amplitude of the CoP displacement and the CoP (the origin of the ground reaction force) in the moving leg were measured in the sagittal plane (CoPy) after instant T3 (initial foot contact).

The length of the first stride was determined by measuring the displacement of the CoPy during the time (stride time) elapsing from T2 (toe off) until the next toe off from the force plate occurring with the same foot.

Kinematic data analysis. The range of ankle motion was determined in the sagittal plane. The ankle angle was calculated between 2 segments, the first of which was defined by the markers placed on the lateral femoral condyle and the lateral malleolus, and the second, by the markers placed on the lateral malleolus and the head of the 5th metatarsus (M5). The maximum extension peak and maximum flexion peak values obtained for the ankle were added. The time at which the maximum ankle extension occurred was determined.

The knee height was determined during the swing phase. The maximum height of the marker placed on the lateral femoral condyle of the moving leg was recorded during the swing phase. The reference position of the knee was the position of the knee before the onset of gait initiation. The difference between these 2 values was calculated to obtain the knee elevation during the swing phase.

The ground clearance, defined as the distance between the floor and the lower part of the foot during the swing phase, was determined. The position of the marker placed on the M5 was determined. This marker was chosen for this purpose because of the risk of foot drag occurring with the equinus foot on the hemiplegic side. The maximum height of the marker placed on the M5 of the moving leg was measured during the swing phase. The reference position of the M5 was its position prior to gait initiation. The difference between these 2 values was calculated to obtain the ground clearance during the swing phase.

To determine the point of initial contact, the positions of the M5 and the lateral malleolus were recorded at time T3. The difference was calculated between the reference positions and the positions reached by these 2 markers at the time of initial foot contact.

Statistical analysis

Data analysis was carried out on 10 trials, starting with each of the lower limbs of each hemiplegic subject (making 20 trials per hemiplegic subject) and 10 trials starting with each of the lower limbs of each healthy subjects (making 20 trials per healthy subject). Gait initiation was compared in each patient between the trials where the affected leg was the supporting leg and those where the sound leg was the supporting leg. A one-way ANOVA was carried out between the groups (healthy subject's leg, patient's hemiplegic leg and patient's sound leg) on phase durations, forces, CoP displacements, stride length, and range of ankle motion. A Student's t-test was carried out (after a normality check) to make paired comparisons between the 2 groups of subjects. A Mann-Whitney test was used to compare the left and right lower limbs of the healthy subjects. When no statistically significant difference was found to exist between steps with the right leg supporting and those with the left leg supporting, the data on all the healthy subjects' steps were combined and compared with the data obtained on the hemiplegic patients' sound and affected legs. Significance level was taken to be at least $p < 0.05$. Gait initiation was analysed depending on which leg was the supporting leg during the monopodal phase. The statistical software program used here was Sigmastat®.

RESULTS

Data analysis

Temporal data. The durations of P1, P2 and P3 did not differ significantly between the left and right legs of the healthy subjects (Table II). In the hemiplegic subjects, the duration of P1 (in ms and as a percentage of the total movement time) was longer when the affected leg was the supporting leg ($p < 0.001$) than with the sound leg. The duration of P2 (in ms and as a percentage of the total movement time) was shorter when the affected leg was the supporting leg ($p < 0.001$) than with the sound leg. The duration of P3 did not differ significantly, depending on whether the hemiplegic patients' affected leg or sound leg was the supporting leg. The durations of P1, P2 and P3, expressed as a percentage of the total movement time, did not differ significantly between the hemiplegic patients using their sound lower limb as the supporting limb and the healthy

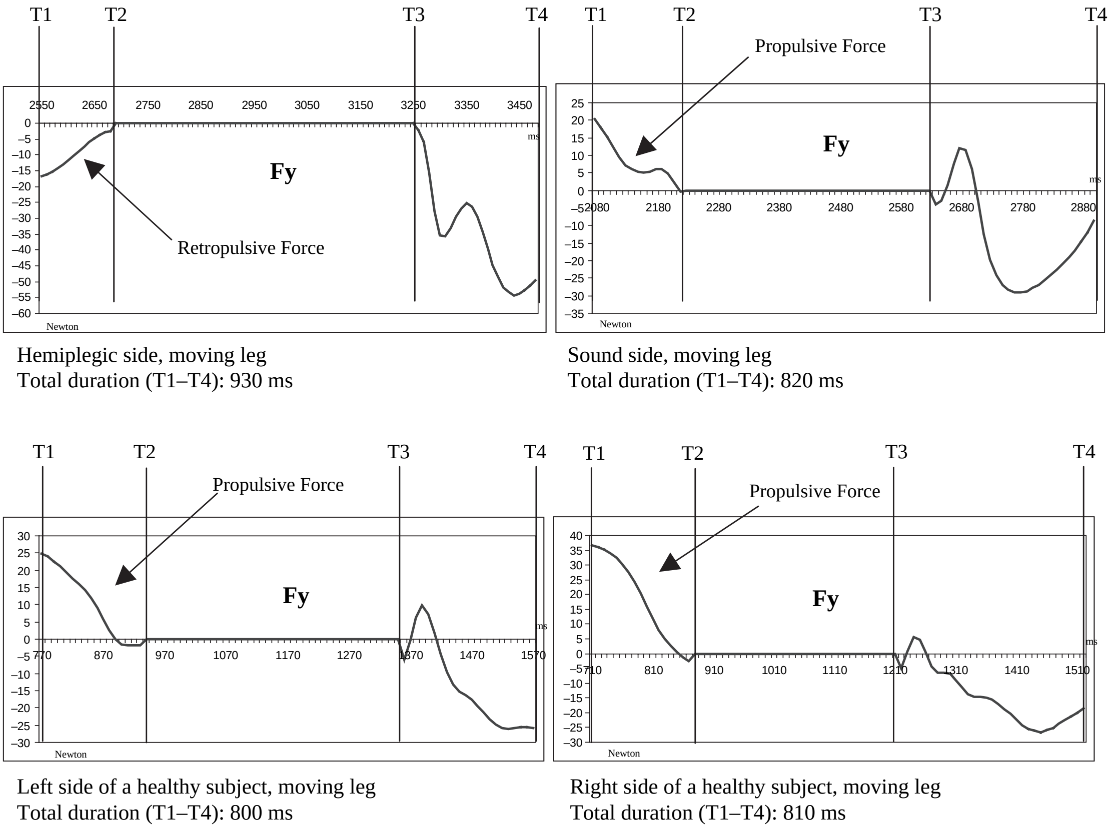

Fig. 3. Area under the curve of Fy (the antero-posterior component of the ground reaction forces in the horizontal plane measured on the hemiplegic side, on the sound side and on the healthy subject's left and right side during the postural phase (P1), the monopodal phase (P2) and the double support phase (P3). In this figure, we have shown only the trace of the moving leg. These values are expressed in Newton seconds. When the value was positive, the force was propulsive. When the value was negative, the force was retropulsive.

subjects. The total movement time did not differ significantly in the hemiplegic patients depending on whether the sound or affected leg was used to initiate gait. The total duration of gait initiation was longer in hemiplegic patients, no matter which leg was the supporting leg, than in normal subjects ($p < 0.05$).

Kinetic data. The area under the curve Fy (Table III) did not differ significantly between the left and right legs of the healthy subjects. The area under the curve Fy during P1 was negative with the hemiplegic leg of hemiplegic subjects. Fy was a retropulsive force in the case of the hemiplegic leg. The value of the area under the curve Fy was greater with the sound lower limb of hemiplegic patients than the healthy subject. The total area under the curve Fy obtained with the hemiplegic lower limb plus the sound lower limb of hemiplegic patients during P1 did not differ significantly from the total value

Table II. *Duration of the gait initiation phases in hemiplegic patients with sound leg or affected leg supporting and in healthy subjects. Results in terms of absolute value and results as a percentage of the total movement time. No statistical differences were observed between the left and right legs of healthy subjects. The total duration was found to have a large SD. That reflects the large SD recorded during the P3 phase when the sound leg was the supporting leg. This pattern was probably due to the loading of the hemiplegic side, which occurred before the swing phase in the sound leg (T4). The loading of the hemiplegic side is probably quite variable from one subject to another*

	Phase P1 (s) Mean (SD) % (SD)	Phase P2 (s) Mean (SD) % (SD)	Phase P3 (s) Mean (SD) % (SD)	Total duration (s) Mean (SD)
Healthy subjects	0.48*,** (0.09) 44.6%* (4.8)	0.39*,** (0.07) 36.5%* (4.5)	0.20*,** (0.02) 18.9% (3.2)	1.07*,** (0.12)
Gait initiation with sound leg (hemiplegic leg supporting)	0.77*,*** (0.10) 53.5%*,*** (4.8)	0.35*,*** (0.09) 24.1%*,*** (6.6)	0.32* (0.10) 22.4% (6.6)	1.44* (0.09)
Gait initiation with affected leg (sound leg supporting)	0.58**,*** (0.10) 38.4%*** (9.9)	0.52**,*** (0.06) 34.7%*** (9.0)	0.53** (0.46) 26.9% (17.6)	1.61** (0.46)

*Healthy/sound leg, $p < 0.05$.
**Healthy/affected leg, $p < 0.05$.
***Sound leg/affected leg, $p < 0.05$.

Table III. *Area under the curve Fy (longitudinal force) during P1, P2 and P3 (Newton seconds). Recording of Fy forces under the sound leg when this leg was the supporting leg and the forces under the hemiplegic leg when this leg was the supporting leg. Area under the curve Fy during P1 depending on the leg used to initiate gait. Area under the curve Fy during P1 depending on the leg used to initiate gait. The area under the curve Fy corresponds to either a propulsive or retropulsive force*

	Area under Fy during P1 Mean (SD)	Area under Fy during P2 Mean (SD)	Area under Fy during P3 Mean (SD)	Total area[1] Mean (SD)
Control subjects	6.8* (2.8)	29.2* (8.4)	13.8 (2.9)	13.5* (3.1)
Sound leg supporting	8.7* (4.8)	20.5* (14.3)	17.4 (7.4)	3.6 (6.8)
Hemiplegic leg supporting	−4.3* (3.6)	11.7* (4.9)	5.8* (2.9)	10.0 (3.3)
Sound leg initiate gait	11.1* (5.2)			
Hemiplegic leg initiate gait	−4.6* (3.9)			

*$p < 0.05$.
[1]Hemiplegic side + sound side area under Fy during P1.

obtained when gait was initiated with the hemiplegic lower limb or the sound lower limb of hemiplegic patients used as the supporting limb. The total area under the curve Fy was greater with the control subjects than with the hemiplegic subjects during P1 ($p < 0.05$). During P2 and P3, the area under the curve Fy was smaller when the affected leg was the supporting leg than with the control subjects or with the sound leg of the hemiplegic subjects, reflecting a lack of propulsion in the affected lower limb.

The distribution of the body weight in hemiplegic patients between the hemiplegic leg (mean 41.6%, SD 6.5) and the sound leg (mean 58.4%, SD 6.5) was asymmetrical, in favour of the sound leg ($p < 0.001$).

The peak amplitude of the CoP displacement at the initial contact of the leg after T3 in hemiplegic patients showed that a backward displacement of the CoPy occurred when the initial contact was made on the hemiplegic side. The mean backward displacement of the CoPy was 9.3 cm (SD 4.5) when the affected leg was the moving leg. There was no such backward displacement of the CoPy at the initial contact in the healthy subject or when the initial contact was made with the sound leg of the hemiplegic patients.

In the healthy group, there was no difference in stride length (mean 60 cm, SD 17) between the left and right legs. Nor was there any difference in the hemiplegic patients' stride lengths between the sound leg (mean 28.5 cm, SD 11) and the hemiplegic leg (mean 28 cm, SD 3). However, the stride length was shorter in hemiplegic subjects than in control subjects ($p < 0.05$).

Kinematic data. The range of ankle motion in the sagittal plane did not differ significantly between the left and the right ankles (mean 17.5°, SD 3.3) in the healthy subjects. The hemiplegic subjects' ankle motion range was greater on the hemiplegic side (mean 31°, SD 7.5) than on the sound side (mean 22.9°, SD 8.8). The peak ankle extension was greater in the hemiplegic leg (mean 24°, SD 8.5) than in the sound leg (mean 13.6°, SD 6) of hemiplegic subjects. The peak in the maximum extension occurred 0.25 seconds (SD 0.19) after T2 in the control subjects and 0.26 seconds (SD 0.19) after T2 in the affected leg of the hemiplegic subjects ($p < 0.05$). There was no significant difference between the affected leg of hemiplegic subjects and the control values. Conversely, in the sound leg of the hemiplegic subjects, the peak in maximum extension always occurred 0.01 seconds (SD 0.04) before T2.

The knee elevation did not differ significantly between the healthy subjects' left and right knee swing phase (mean 2.3 cm, SD 0.4). The knee elevation was greater with the hemiplegic leg (mean 6.2 cm, SD 1.2) of the hemiplegic subjects than with their sound leg (mean 3 cm, SD 1.4) or the legs of healthy subjects ($p < 0.05$).

The ground clearance did not differ significantly between the hemiplegic leg (mean 3.8 cm, SD 1.5) and sound leg (mean 3.3 cm, SD 0.9) of hemiplegic patients.

The initial contact (T3) made by the control subjects and by the sound leg of the hemiplegic subjects was a heel strike (Table IV). The initial contact made by the affected lower limb of the hemiplegic subjects was a flat-foot contact.

DISCUSSION

The aim of this study was to assess the kinetic and kinematic characteristics of gait initiation during the various gait initiation phases in hemiplegic patients after stroke in comparison with healthy control subjects.

The total duration of gait initiation (from T1 to T4) recorded in this study was approximately the same, whether the hemiplegic leg or the sound leg of hemiplegic patients served as the supporting leg. These results are consistent with the hypothesis put forward by Brenière & Do (13) in line with the inverted pendulum model, that the total duration of gait initiation is invariant.

However, some specific effects of hemiplegia were observed here during gait initiation. For example, the respective contributions of the P1 and the P2 to the duration of gait initiation differed significantly, depending on whether the hemiplegic leg or the sound leg of the hemiplegic patients was used as the supporting limb. The P1 was longer when gait was initiated with the hemiplegic leg rather than the sound leg of the hemiplegic patients; whereas the P2 was shorter in the case of steps where the hemiplegic leg rather than the sound leg of the hemiplegic patients was used as the supporting leg. During gait initiation, hemiplegic patients therefore tend to reduce the duration of the P2 when the hemiplegic leg is the supporting

Table IV. *Height (mean (SD)) of the fibular malleolus and the 5th metatarsus (M5) at instant T3 (initial contact)*

	Height of fibular malleolus at T3 (cm)	Height of M5 at T3 (cm)
Control subject	−0.1* (0.3)	2.0* (1.0)
Sound leg	0.4* (0.2)	1.8* (0.5)
Affected leg	0.6* (0.6)	−0.3* (0.3)

*$p < 0.05$.

leg, whereas they increase the duration of the P2 when the sound leg of hemiplegic patient is the supporting leg in comparison with healthy subjects. This result is in agreement with those published by Hesse et al. (19).

Several hypotheses may help to explain why the P1 was longer when the hemiplegic leg was the supporting one than when the sound leg of hemiplegic patients or either leg of healthy subjects was the supporting leg. First, the distribution of the body weight between the 2 legs was asymmetrical, since the body weight was mainly supported by the sound leg in the hemiplegic subjects during the P1. Brunt et al. (18) observed a similar asymmetrical body weight distribution. Since the body weight is supported mainly by the sound leg in hemiplegic patients, it takes longer to transfer the body weight from their sound leg onto the hemiplegic leg. Hesse et al. (19) and Kirker et al. (20) reached similar conclusions. Kirker et al. (20), who studied the EMG activity of the hip abductor and adductor muscles in hemiplegic patients, reported that the EMG activity decreased in the hemiparetic muscles and that the onset latencies of these muscles were lengthened during the transfer of the body weight onto the supporting leg (the sound or hemiplegic leg). This change in the pattern of muscle activity may be responsible for the increase in the duration of the P1. The third possible explanation might be that due to the lack of equilibrium in the hemiplegic leg, transferring the body weight onto the hemiplegic side may require more time. However, further studies are required to test these hypotheses.

The duration of the P2 was found to be shorter when the hemiplegic leg rather than the sound leg of hemiplegic patients or either leg of healthy subjects was the supporting leg. This is consistent with the data published by Hesse et al. (19). It is possible that the duration of P2 in the hemiplegic leg may have decreased because of equilibrium control impairments, and especially because of the lack of stability, which occurs when the hemiplegic leg is the weight-bearing leg. When the sound leg of hemiplegic patients was used as the supporting leg, the duration of the P2 increased in comparison with the hemiplegic leg or either leg of healthy subjects. The P2 probably increased in order to compensate for the propulsion deficit present on the hemiplegic side.

The horizontal ground reaction forces exerted in the sagittal plane, which are responsible for the forward propulsion of the CoG (8, 15, 16) during gait initiation were studied. The kinetic analysis confirmed the asymmetrical effects of hemiplegia during gait initiation. During the P1, the Fy values on the hemiplegic side were negative in comparison with the sound side of hemiplegic patients or the legs of healthy subjects, which means that the forces were directed backwards, or in other words, that they were retropulsive; whereas the Fy values were found to be positive and to be higher on the sound side of hemiplegic patients than in the healthy subjects. The reason why the forces exerted by the affected leg were exerted backwards can be explained in terms of the equinus varus. But this is not the only explanation, since Couillandre et al. (29) have reported that forward directed forces can occur even with tiptoe-walking. According to Couillandre, the equinus places the CoP on the forefoot. In hemiplegic patient with equinus foot, the projection of the CoG is therefore located behind the CoP. If the projection of the CoG is in front of the CoP, then the forces will be exerted forward and will be propulsive. This was found to be the case on the sound side of hemiplegic patients and in healthy subjects. If, on the contrary, the projection of the CoG is located behind the CoP, then the forces will be exerted backward and will be retropulsive. This was the case on the patient's hemiplegic side. In this case, it can be hypothesized that during the P1, the CoG projection returns to the CoP position in hemiplegic patients.

The increase in the total Fy propulsive forces exerted by the sound leg of hemiplegic patients will compensate for the retropulsive forces exerted by the hemiplegic leg during the P1.

During the, the total Fy values did not differ when gait was initiated with the hemiplegic leg, while the sound leg of hemiplegic patients served as the supporting leg. This may have resulted from the step onset time being delayed (i.e. from the P3 being prolonged) when the affected leg was to be used as the supporting one. This asymmetrical posturomotor strategy reduces the time required to control equilibrium during the P2 on the affected leg, that is when the patient is highly unstable.

At initial contact on the hemiplegic side, the displacement of the CoPy was found to be in the backward direction, whereas when the initial contact occurred on the sound side of hemiplegic patients, and on both sides in the case of the healthy subjects, it was directed forward. This is in line with the backward shift of the CoPy occurring during the end of gait described by Winter (30). It therefore seems likely that at initial contact on the affected side, hemiplegic patients act as if they were reaching the end of gait, and then they have to initiate gait all over again. From the clinical point of view, this pattern may be attributable to the fact that initial contact on the hemiplegic side occurs with a flat foot and not with the heel.

The kinematics of gait initiation have not been documented so far in patients after stroke, except for a preliminary study on one patient (28). In the present study, it was established that the range of ankle motion and the peak of maximum ankle extension were greater in the hemiplegic leg than in the sound leg of hemiplegic patients or the legs of healthy subjects. Maximum ankle extension on the affected side occurred during the swing phase. The increase in the range of ankle motion observed on the hemiplegic side, which was an unexpected finding, might be attributable to a high level of triceps spasticity, inducing an increase in ankle extension during the swing phase.

This means that the increase in ankle extension occurring during the swing phase was greater than the decrease in ankle flexion occurring during the support phases.

Although a peak ankle extension occurred during the swing phase in the hemiplegic patients, the ground clearance during the swing phase was the same in both the hemiplegic leg and the sound leg of hemiplegic patients. This was due to the fact that these patients raised their knee higher on the hemiplegic side than on the sound side of hemiplegic patient during the swing phase in order to prevent foot drag.

The initial contact showed an asymmetrical pattern between the hemiplegic patients' legs. The initial contact was performed with the heel by healthy subjects, as well as by hemiplegic subjects using their sound leg. When using the affected leg, these patients' initial contact was performed with a flat foot. This difference may be attributable to the spasticity of the triceps, which prevents the ankle dorsiflexors from being activated, especially during the swing phase.

The results of the present kinematic study therefore confirm the qualitative clinical findings obtained on hemiplegic subjects, and provide additional data with which it is possible to describe the gait initiation strategy used by these stroke patients in quantitative terms.

Conclusion

In conclusion, in the present study, some considerable changes in phase duration, CoP displacement, and ground reaction forces, as well as in the kinematic parameters were observed in stroke patients in comparison with control subjects. These data suggest that hemiplegic patients develop asymmetrical adaptive posturo-motor strategies to compensate for their impairments.

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