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SHORT COMMUNICATION

RELIABILITY OF LOWER LIMB KINEMATICS, MECHANICS AND ENERGETICS DURING GAIT IN PATIENTS AFTER STROKE

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Objective: **To assess the reliability of kinematic, mechanical and energetic gait variables at short (1 day) and medium (1 month) intervals in adult patients after stroke.**
Design: **Prospective study.**
Subjects: **Ten patients with chronic post-stroke (mean age 53.5 years; age range 25–80 years).**
Methods: **Three-dimensional gait analysis was performed 3 times in these subjects: at baseline (T_0), after 1 day (T_1) and after 1 month (T_2). The reliability of the gait analysis was tested by comparing gait variables measured at T_1 and T_0 (1 day interval), at T_2 and T_0 (1 month interval). The inter-session reliability of kinematic, mechanical and energetic variables was calculated by intra-class correlation coefficient (ICC).**
Results: **The reliability of kinematic variables ranged from excellent to moderate (ICC $\geq$ 0.51), except for the ankle position at heel strike (ICC = 0.44). The reliability of mechanical and energetic variables ranged from excellent to good (ICC $\geq$ 0.71). The most reliable variable was external mechanical work (ICC = 0.96). The kinematic, mechanical and energetic variables did not change significantly between T_0, T_1 and T_2 (repeated-measures analysis of variance).**
Conclusion: **Kinematic, mechanical and energetic gait variables present good reliability when measured at 1 day and 1 month intervals in adult patients after stroke.**

Key words: stroke, gait analysis, reliability.

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INTRODUCTION

The gait laboratory can provide an objective assessment of walking using quantitative measurements of kinematic, mechanical and energetic variables. These variables are useful for treatment planning and clinical research. It is therefore important to know when a variation between measurements of these variables is the result of a gait modification and when it is related to the variability of the measurement used.

The reliability of gait analysis to date has been considered largely in healthy subjects (1), with little exploration among patients with known gait impairments or disabilities. The reliability of spatio-temporal and kinematic gait parameters has been studied in subjects with idiopathic scoliosis (2) and in children with cerebral palsy with hemiplegia (3). In adult patients after stroke, Yavuzer et al. (4) showed the short-term reliability of these variables during 2 sessions on the same day.

Patients after stroke form a large population with gait disabilities. They often undergo movement analysis to study their gait disturbances, e.g. through daily clinical practice to plan surgery treatment or through clinical research studies. No study has yet evaluated the medium-term reliability of gait analysis among adult patients after stroke. This study aims to assess the reliability of kinematic, mechanical and energetic gait variables in patients after stroke at short (1 day) and medium (1 month) intervals.

MATERIALS AND METHODS

Study population

Ten patients with chronic post-stroke, 8 men and 2 women, were enrolled in the study. The inclusion criteria were: hemiparesis secondary to stroke, time since stroke greater than 6 months, and ability to walk independently without an assistive device on a treadmill for a sufficient time to complete a metabolic analysis (around 2 min). The median age was 53.5 years (range 25–80 years), median time since stroke was 22 months (range 6–125 months), and median Stroke Impairment Assessment Set (5) score was 57.5 (range 44–75). Other than an additional gait assessment, this study made no changes to medical treatments being received by the subjects post-stroke. The study was approved by the local ethics committee and all patients provided written informed consent.

Instrumented gait analysis

Gait analysis was performed following the protocol described by Stoquart et al. (6). Three-dimensional kinematic analysis, mechanical and energetic measurements were conducted as patients walked on a force-measuring treadmill (Mercury-LTmed, HP-Cosmos, Nussdorf-Traunstein, Germany). Segmental kinematics was measured using the Elite system (BTS, Milan, Italy). Six infrared cameras measured at 100 Hz the co-ordinates in the 3 spatial planes (frontal, sagittal and transverse) of 20 reflective markers positioned at specific anatomical landmarks (7). These measurements allowed for computation of the angular displacement of the hip, knee and ankle during the walking cycle. Ground

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reaction forces (GRF) were recorded by 4 strain gauges, located under each corner of the treadmill. The total positive mechanical work (W_{tot}) performed by muscles during walking was divided into 2 components: (*i*) the external work (W_{ext}) performed to move the centre of body mass (COM_b) relative to the surroundings; and (*ii*) the internal work (W_{int}) performed to move body segments relative to COM_b. The metabolic cost of walking was determined by the patient's oxygen consumption and carbon dioxide production measured throughout the treadmill test. The energy expended above the resting value was divided by the walking speed to obtain the net energy cost of walking (C, J kg^{-1} m^{-1}).

Protocol

The subjects were tested during 3 sessions: at baseline (T_0), after 1 day (T_1) and after 1 month (T_2). The reliability of the gait analysis was tested by comparing gait variables measured at T_1 and T_0 (1 day interval), at T_2 and T_0 (1 month interval).

Anthropometric measurements and data were collected by the same experienced physician. To reduce the variability of markers positioning, he placed the marker following anatomical landmarks. He then measured the distances required by the model (7) and adapted the markers' positioning to keep these distances constant across the 3 gait analyses. At T_0, subjects were asked to walk on the treadmill at a self-selected, comfortable pace, which was then kept constant for the remaining 2 sessions (T_1, T_2). For each session, kinematic and mechanical data were recorded from 10 consecutive gait cycles and averaged. The mean values were used for statistical analysis. A set of kinematic data was selected during the gait cycle, as proposed by Benedetti (8).

Statistics

The inter-session reliability of kinematic, mechanical and energetic variables was calculated by the one-way random intra-class correlation coefficient (ICC) using one-way analysis of variance (ANOVA) (9). A one-way repeated-measures ANOVA was computed to study the effect of time (T_0, T_1, T_2) on gait analysis variables.

RESULTS

The kinematic, mechanical and energetic variables did not change significantly between T_0, T_1 and T_2. This confirms that the gait of our patients with chronic stroke was stable and did not change in the 1-month period between T_0 and T_2.

The reliability of kinematic variables (Table I) ranged from excellent (ICC values ≥ 0.91 (10)) to moderate (ICC values ≥ 0.51) except for the ankle position at heel strike (ICC = 0.44). The most reliable variable was the maximum knee flexion in swing phase (ICC = 0.93). The reliability of mechanical and energetic variables ranged from excellent to good (ICC values ≥ 0.71). The most reliable variable was W_{ext} (ICC = 0.96). The short-term (1 day) and medium-term (1 month) reliability were similar (paired *t*-test, $p > 0.05$).

In order to assess the intra-subject reliability, the absolute differences between variables recorded at T_0 and T_2 were computed. The mean of these absolute differences for the kinematic variables ranged from 1° to 5°. The 95th percentile (p95) of these differences ranged from 4° to 14°. The mean of the absolute differences between T_0 and T_2 for the mechanic and energetic variables ranged from 0.01 to 0.63 J kg^{-1} m^{-1}. The W_{ext} presented the lowest p95 (0.03 J kg^{-1} m^{-1}).

Table I. *Inter-session intra-class correlation coefficients (ICC), repeated-measures analysis of variance (ANOVA), mean absolute difference and 95th percentile of kinematic, mechanical and energetic variables*

	ICC_{T0-T1}	ICC_{T0-T2}	ANOVA *p*-value	Absolute difference T_0/T_2 Mean	p95
Kinematics					
Pelvic minimum sagittal position	0.70	0.74	0.91	3	9
Pelvic maximum sagittal position	0.72	0.52	0.27	3	10
Hip flexion at heel strike	0.86	0.84	0.47	5	12
Hip maximum extension in stance phase	0.58	0.51	0.90	5	13
Knee flexion at heel strike	0.71	0.60	0.31	4	10
Knee maximum flexion at loading response	0.84	0.74	0.85	4	11
Knee maximum extension in stance phase	0.58	0.56	0.62	5	14
Knee maximum flexion in swing phase	0.94	0.93	0.52	4	11
Ankle flexion at heel strike	0.64	0.44	0.06	5	13
Ankle maximum dorsiflex in stance	0.63	0.76	0.28	4	10
Ankle maximum dorsiflex in swing	0.84	0.67	0.37	2	8
Average frontal pelvic position	0.80	0.63	0.97	1	4
Average frontal hip position	0.69	0.80	0.31	2	5
Average transversal pelvic position	0.85	0.65	0.76	2	8
Average transversal hip position	0.62	0.71	0.11	3	7
Average transversal ankle position	0.83	0.87	0.48	2	6
Mechanics					
W_{ext}	0.96	0.99	0.18	0.01	0.03
W_{int}	0.89	0.92	0.06	0.02	0.07
W_{tot}	0.85	0.84	0.23	0.08	0.35
Energetics					
Cost	0.92	0.79	0.61	0.63	1.40

The difference of the kinematic variables is expressed in degrees and the difference of the mechanical and energetic variables in J kg^{-1} m^{-1}.
T_0: at baseline; T_1: after 1 day; T_2: and after 1 month.

DISCUSSION

The present study revealed good reliability of kinematic, mechanical and energetic gait variables among adult stroke patients.

The W_{ext} is the most reliable variable. The p95 difference (0.03 J kg^{-1} m^{-1}) corresponds to only 7% of the mean W_{ext}. This means that a difference greater than 7% between 2 successive measures in a single subject is significant. This finding emphasizes the clinical importance of using W_{ext} as an outcome variable. Regarding the energy cost of walking (*C)*, a high ICC of 0.97 was previously reported in patients after stroke completing 2 trials on the same day (11). The good reliability of the *C* in the short and medium terms is confirmed in this study. However, *C* is less reliable than W_{ext}. The average difference is 0.6 J kg^{-1} m^{-1}, corresponding to 14% of the mean *C* and similar to values reported in children with cerebral palsy (12). Yavuzer et al. (4) reported a high ICC for kinematic variables (range 0.92–0.98) performed during 2 sessions on the same day. Similarly, our study demonstrated an excellent to moderate reliability of these variables at 1 month interval. This could be explained by the effort made to optimize the marker positioning: the same physician placed the marker keeping the distance between markers constant and performed anthropometric measurements at T_0, T_1 and T_2. Indeed, proper marker positioning is fundamental to allow reliable and valid movement analysis (13, 14). This could also be related to the great number ($n=10$) of the gait cycles studied (15). However, the mean p95 difference for kinematic variables was 10°, meaning that a difference lower than 10° between 2 successive measurements in a single subject must be interpreted with caution. Finally, contrary to previous studies (2–4), the results of this study showed the reliability of kinematic variables to be similar in the frontal, sagittal and transverse planes. The poor reliability for the ankle position at heel strike could be explained by the fact that this short multi-segment joint is determined by only 2 markers.

In conclusion, kinematic, mechanical and energetic gait variables present good reliability when measured at 1 day and 1 month intervals in adult patients after stroke. The W_{ext} is the most reliable variable.

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