Effects of robotic gait rehabilitation on biomechanical parameters in the chronic hemiplegic patients

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Résumé :

L'hémiplégie est une perte plus ou moins complète de la motricité volontaire d'un hémicorps suite à une lésion cérébrale, entraînant généralement des altérations de l'appareil locomoteur avec des troubles persistants du mouvement et de la posture. Nous nous sommes intéressés pour cette étude au schéma de marche dit « stiff knee gait » avec pour objectif principal de mettre en évidence le rôle d'une rééducation robotisée dans l'amélioration ou la modification du schéma de marche chez des adultes hémiplégiques chroniques. Les données ont été recueillies par un système d'analyse du mouvement (Vicon® - Oxford Metrics, Oxford, UK) afin de réaliser une analyse quantifiée de la marche (AQM) avant et après une rééducation robotisée (Lokomat®) intensive de 4 séances par semaine pendant 5 semaines sur 10 adultes hémiplégiques chroniques. Les résultats montrent une amélioration significative des paramètres locomoteurs (vitesse de marche, longueur du pas, temps du double et du simple appui) et de la cinématique du genou du côté hémiplégique. Cette première étude montre bien l'importance et l'utilité de la rééducation robotisée comme aide à la rééducation du schéma de marche chez des adultes hémiplégiques chroniques. En effet, les patients hémiplégiques semblent adopter de nouvelles stratégies de marche.

Mots clés : Hémiplégie chronique, Rééducation de la marche, Orthèse de marche, Cinématique du genou, Paramètres locomoteurs.

1. Introduction

The recovery of locomotor capacities is one of the primary objectives in the rehabilitation of patients with locomotor disorders. Therapeutic interventions for such conditions seek to minimise the consequences of a lesion in general [9], and provide compensatory strategies so as to improve a patient's functional independence (mobility, self-care, social integration).

In recent years, robotically driven orthoses, such as the Lokomat® (Hocoma AG, Volketswil, Switzerland) have emerged as a promising new technology in the rehabilitation of patient mobility. Purposely built to support sensorimotor learning, these systems of rehabilitation assisted by robotics are increasingly proposed to patients with locomotor disorders following cortical or sub-cortical lesions. Based on the body weight supported treadmill training (BWSTT) principle, their main purpose consists to reacquire functional gait through an intensive and repetitive simulation of the different phases of gait and a sensory stimulation feeding proprioceptive feedback [2, 5]. These sensorimotor informations allow cortical and subcortical reorganization of the patients with spinal cord or brain lesions. By repeating intensively same movement, the circuits involved in the realization of locomotor movements will be activated allowing the nervous system to establish and / or re-establish links between the motor centers and sensory pathways which may be affected in varying degrees depending on the lesion. Indeed, numerous studies have indicated that task-specific mass is often the most reliable and fastest method for improving patient locomotor function [6-7, 10-11, 13].

The research conducted with hemiplegic populations [1, 4-5, 12, 14] has demonstrated that automated gait retraining systems have a positive global effect upon walking speed and endurance (in terms of both distance and time) as well as improving stride length, frequency and symmetry. Patients have also been observed to have improved muscle power and balance in addition to reduced heart rate and oxygen consumption. The use of an automated gait retraining device as part of an individually adapted rehabilitation program may thus enhance treatment programs, assisting the recovery of functional mobility. Used in combination with traditional rehabilitation approaches, robotically driven gait orthoses may extend the intensity of therapy and improve the long-term effects of rehabilitation. Such tools should not be considered as a replacement for existing methods of rehabilitation. Robotic gait devices must only be used an adjunct to existing therapeutic techniques.

The principal objective of the current study was to demonstrate how automated gait retraining changes biomechanical parameters through the course of locomotor rehabilitation in adult patients with chronic hemiplegia. Hemiplegia is a more or less complete loss of a hemicorps voluntary motor following a brain injury, usually resulting in alterations of the locomotor system with persistent disorders of movement and posture. The focus here is placed upon patients with stiff knee gait, a condition where swing-phase knee flexion is considerably diminished. Patient gait patterns were often characterized by hyperflexion during the swing phase in a measure serving to facilitate foot clearance.

The expected results were that the stroke patient would present a different organization from a mechanical point of view after rehabilitation mainly on locomotor parameters such as the kinematics of the knee.

2. Methods

2.1. Participants

Gait analysis data were obtained from 10 chronic right hemiplegic patients (ischemic stroke; 12 years ± 2.1 after stroke) aged 64 years ± 1.2 with a stiff knee gait. Each participant needed to be able to walk at least 60 meters to be included in the study. In order to see the actual effects of this rehabilitation, all subjects were not receiving daily physiotherapy interventions and had not undergone surgical treatment or received recent injections botulinum toxin at the time of assessment.

2.2. Procedure

Clinical gait analysis was performed before and after a robotic rehabilitation (Lokomat®Pro) four intensive sessions per weeks of 30 minutes effective during five weeks. Before each clinical gait analysis, the participants were informed of the progress of the study and gave their signed consent. They walked barefoot without walking aids and in underwear at their preferred speed in a minimum of ten trials on a 10 m x 0.60 m gait track. Data were collected by a motion analysis system with 8 infrared cameras, sampling frequency of 200 Hz (VICON® – Oxford Metrics, Oxford, UK) and 4 force platforms (AMTI®, 0.60 m x 0.60 m) in order to provide a clinical gait analysis.

2.3. Data analysis and statistical methods

Data were processed using VICON-Nexus® acquisition software (Oxford Metrics, Oxford, UK) and Motion Inspector® software (Biometrics France, Orsay, France) in order to reconstruct an appropriate biomechanical model for each subject reflecting the trajectory of the retro-reflective markers. This reconstruction allows us then: i) to calculate locomotor events in order to identify the different walk cycles phases and ii) to recalculate the joint centers of each segment in order to identify mainly the amplitudes of the knee. After establishing that each variable was normally distributed (according to a Shapiro-Wilk test), the following statistical analyses were conducted: i) an ANalysis Of VAriance (type III) using the R software in order to observe significance between the data before and after rehabilitation for locomotor parameters and kinematic data, ii) a coefficient of variation (CV) of the ensemble average of the knee angle for each patient with knee angle (left and right) normalized by gait cycle. This coefficient of variation allows calculate the mean variability over the stride period between before and after rehabilitation and express it as a percentage of the mean value of the signal. In all cases, results were considered statistically significant where $p \leq 0.05$.

3. Results

3.1. Locomotor parameters data

The results show a significant improvement of the different parameters studied whether at the gait (*cf.* Table I) or the postural stability (*cf.* Table II). Indeed, we observed both an increase in speed gait and step length associated with a decrease in the cadence and step width mainly on the hemiplegic side, but also a decrease in the double support time associated with an increase in the single support time on the hemiplegic side.

3.2. Kinematic data

The results show (*cf.* Figure 1) i) healthy side (left) a modification (no significant statistically) of the joint amplitude whether at the flexion in stance phase (pre 19.89°±0.79 *vs.* post 18.76°±2.06) or at the flexion in swing phase (pre 61.02°±3.01 *vs.* post 60.05°±1.89) and ii) hemiplegic side (right) a significant decrease of the joint amplitude whether at the first flexion (pre 34.32°±0.75 *vs.* post 18.04°±1.78) or the second flexion (pre 70.01°± 0.55 *vs.* post 59.14°± 1.80). In addition, there was a significant increase in the coefficient of variation (CV) on the hemiplegic side (pre 11% *vs.* post 24%) which reflects greater variability between different cycles.

4. Discussion

The aim of this study was to determine the effect of robot gait rehabilitation on biomechanical parameters in chronic hemiplegic adults. This first study, although performed on a limited number of patients and not including a control group, revealed consistent changes in the segmental organization of gait.

The observed results confirm those reported by previous studies [1, 3-5, 12, 14]. Indeed, all patients were seen to adopt new gait strategies, overt changes that were observed in terms of locomotor parameters and gait patterns (particularly marked at the level of the knee). Statistically significant increases in gait speed and step length were identified, factors which were also associated with a significant decrease in cadence and step width on the hemiplegic side. In addition to this, patients showed statistically significant improvement in gait symmetry. Reduced lateral movement of the body during weight transfers was observed as the duration of the double support time decreased and single support time on the hemiplegic side increased. Collectively, these modifications to patient gait patterns brought about improved postural stability and control of dynamic balance. Relatively speaking, these gait patterns are presented as being more efficient in terms of mechanical energy, effort and joint loads. Modeling by inverse dynamics is warranted in order to confirm this hypothesis.

Overall, the results from the knee kinematic analysis and comparison of locomotor parameters indicate an important correlation between the knee flexion and the quality of patient gait. Prior to the robotic gait retraining program, patient gait patterns were often characterized by hyperflexion during the swing phase in a measure serving to facilitate foot clearance. Following the rehabilitation program, knee flexion on the hemiplegic side was considerably reduced during both swing and stance phases. The recorded range of motion is similar to those observed at the knee in healthy control subjects during normal paced walking at approximately 20° during stance phase and 60° during swing phase [8]. This progression would indicate that patients tend to acquire more typical gait patterns through the course of robotic gait retraining.

The results of this work support the use of robotic gait orthoses such as the Lokomat® in the rehabilitation of patients with hemiplegia. These robotic gait retraining systems provide a valuable means to deliver graded sensorimotor retraining. Offering the possibility for extended periods of exercise, continuous repetition of gait cycles allows for improved consolidation of effective locomotor patterns. The proprioceptive, kinesthetic and vestibular stimulation inherent in this activity equally provide an integral component to patient rehabilitation, thereby facilitating the development of healthy postural responses and adaptive motor behavior.

At the same time, the limits of these systems must be recognized and such tools should not be considered as a replacement for existing methods of rehabilitation. Robotic gait devices must only be used an adjunct to existing therapeutic techniques. Further to the stimulation of the sensory system and repetitive training of gait patterns provided by automated gait retraining, personalized physical therapy interventions are required to address more specific aspects of locomotion such as initiating gait, climbing stairs, overcoming obstacles, adapting to different surfaces (soft, hard, sloped etc.) and coming to a halt.

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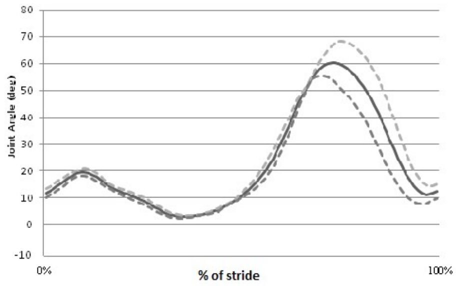
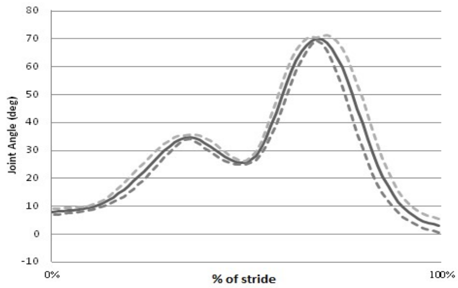
Table I.

		Pre-rehabilitation	Post-rehabilitation	
Speed ($m.s^{-1}$)		0.84 ± 0.13	1.19 ± 0.40	*
Cadence (step/min)		1.09 ± 0.30	0.96 ± 0.10	*
Length (m)	Left	0.89 ± 0.19	0.92 ± 0.18	
	Right	0.82 ± 0.17	0.88 ± 0.14	*
Width (m)	Left	0.13 ± 0.09	0.09 ± 0.03	*
	Right	0.19 ± 0.10	0.14 ± 0.07	*

Table II.

		Pre-rehabilitation	Post-rehabilitation	
Single support time (s)	Left	0.42 ± 0.09 (36.1% ± 3.2)	0.45 ± 0.12 (35.8% ± 4.6)	
	Right	0.39 ± 0.14 (29.3% ± 2.4)	0.43 ± 0.10 (33.7% ± 2.7)	*
Double support time (s)	Left	0.40 ± 0.05 (23.9% ± 4.03)	0.38 ± 0.09 (24.2% ± 3.9)	
	Right	0.44 ± 0.07 (30.7% ± 3.6)	0.39 ± 0.10 (26.3% ± 4.2)	*

Figure 1.

<table>
<tr><th></th><th>Knee joint angle (left)</th><th>Knee joint angle (right)</th></tr>
<tr><td>Pre-rehabilitation</td><td>CV = 20%

</td><td>CV = 11%

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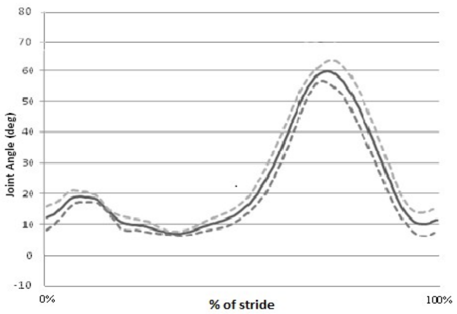
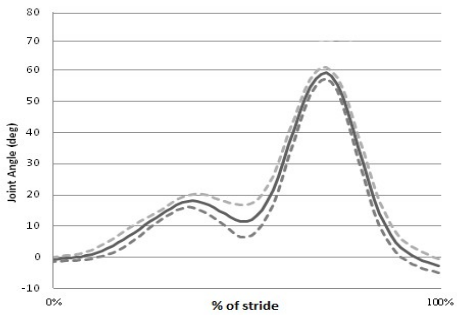
<tr><td>Post-rehabilitation</td><td>CV =22.5%

</td><td>CV = 24%

</td></tr>
</table>

Legends to figures and tables:

Figure 1. Ensemble average of the knee angle. The solid line is the mean of the joint angles as calculate over the stride period. The dotted line represents one SD either side of the mean. The CV's are as indicated on the curves.

Ensemble des moyennes de l'angle du genou. La ligne continue correspond à la moyenne des angles calculés par rapport à la période du cycle. Les lignes pointillées représentent les écartstypes. Les CV sont indiqués au-dessus des courbes.

Table 1. General gait parameters between before and after rehabilitation.

Paramètres généraux de la marche entre avant et après la rééducation.

* = significant at $p \leq 0.05$

Table 2. Postural stability indices between before and after rehabilitation.

Indices de stabilité posturale entre avant et après la rééducation.

* = significant at $p \leq 0.05$