BIO Web of Conferences **1**, 00092 (2011)
DOI: 10.1051/bioconf/20110100092

Lower Limb Voluntary Movement Improvement Following a Robot-Assisted Locomotor Training in Spinal Cord Injury

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Abstract

Individuals with spinal cord injury (SCI) suffer from severe impairments in voluntary movements. Literature reports a reduction in major kinematic and kinetic parameters of lower limbs' joints. A body weight support treadmill training with robotic assistance has been widely used to improve lower-extremity function and locomotion in persons with SCI. Our objective was to explore the effects of 4-weeks robot-assisted locomotor training on voluntary movement of the ankle musculature in patients with incomplete SCI. In particular, we aimed to characterize the therapeutic effects of Lokomat training on kinematic measures (range of motion, velocity, smoothness) during a dorsiflexion movement. We hypothesized that training would improve these measures. Preliminary results show an improvement of kinematic parameters during ankle dorsiflexion voluntary movement after a 4-weeks training in the major part of our participants. Complementary investigations are in progress to confirm these results and understand underlying mechanisms associated with the recovery.

1. Introduction

Individuals suffer from neurological diseases like spinal cord injury (SCI) present several sensory-motor impairments. Literature reveals muscle weakness [10, 11], abnormal increase in muscle tone (i.e., spasticity) [5, 10] and abnormal co-activation in muscular patterns between agonists and antagonists [7, 11]. In incomplete SCI ambulatory patients, these symptoms drive a reduction of voluntary movement at the ankle joint. During locomotion, a reduced ankle dorsiflexion in swing phase is systematically observed and associated with the foot drop syndrome [12]. This impairment participates to poor quality of locomotion and reduced functional independence in patients.

Over the past few years, the Lokomat® (Hocoma AG, Volketswill, Switzerland), a driven gait orthosis (DGO) device on a treadmill with a body-weight support, was developed for locomotor therapy in neurological diseases. The Lokomat delivers a guidance for the legs in a physiological pattern through a bilateral motorized exoskeleton device. This task-specific practice of stepping is knew to enhance the afferent feedback associated with normal locomotion and induce plasticity of spinal locomotor centers [2]. Furthermore, this device has the advantage of increasing the total duration of training and reducing the labor-intensive requirements of the manual-assisted treadmill intervention.

Many studies show that Lokomat training help SCI patients to improve their over-ground speed, gait endurance, spatio-temporal gait pattern and EMG temporal activation patterns [8, 6, 14]. More specifically, a recent work reveals a reduction of the spasticity in the ankle flexor and extensor muscles following a 1-month training [9].

The aim of this study was to evaluate the specific effect of a 1-month Lokomat training on spastic ankle kinetic and kinematic parameters during voluntary dorsiflexion movement.

2. Method

2.1. Participants

Eight ambulatory SCI subjects (mean age 51±6.12, four females and four males) with incomplete motor function loss and different degrees of ankle muscle spasticity participated in this study. Per protocol, patients performed clinical evaluations to assess their functional ambulation capacity and help interpret clinical research results. Clinical evaluations in-

No.	Injury level	MAS	TUG	10MWT	6MWT
1	C6-C7	2	18.79	18.25	177.22
2	C3-C4	3	18.23	15.90	238.24
3	T7	2	53.32	53.29	33.82
4	T7	2	99.99	185.88	–
5	C2-C5	2	9.73	9.40	309.71
6	C5-C7	4	17.23	11.49	265.35
7	T5-T7	2	15.49	13.66	224.24
8	C4-C5	1	12.60	9.40	345.99
	Mean	2.25	30.67	39.74	227.80
	SD	0.78	27.48	53.65	88.32

Table 1: Clinical characteristics and evaluations of all SCI participants. Patient 4 was nor able to perform the 6MWT test.

cluded the Timed Up and Go test (TUG), the 10-meter walk (10MWT), and the 6-minute walk test (6MWT). TUG evaluates the functional ambulation and balance by measuring time taken by the subject to stand up from and sit back to an armed-chair for a walking distance of 3-meters [3]. 10MWT is used to evaluate walking speed by measuring time spent for a walking distance of 10 meters [4]. 6MWT is used to assess walking endurance by measuring distance covered by 6-minutes of walking [13]. Muscle tone at the ankle joint was also evaluated using a 5-point scale based on the modified Ashworth (MAS) [1]. Scores are presented in Table 1.

2.2. Procedure

All participants performed a robot-assisted locomotor training for 4 weeks. Gait training was provided three days per week using a 1-hour training period including set-up time with up to 30 minutes of training during a single session. Over the training, we increased the treadmill speed, reduce the guidance force (i.e., level of gait assistance for each leg between full and zero guidance force) and the body-weight support as tolerated by patient.

Subjects were evaluated four times: at baseline, 1- , 2- and 4-weeks after training. They were seated and secure in an experimental chair with the ankle strapped to the foot rest. Subjects were asked to produce two repeated voluntary movements of the ankle from full plantarflexion to dorsiflexion at their maximum speed. We also measured the isometric maximal voluntary contraction (MVC DF) of ankle flexors at the joint position of 90 degrees during 5 sec. Ankle angular position and torque were recorded respectively by a potentiometer and a torque transducer.

2.3. Data reduction

Angular velocity and acceleration were calculated from the first and the second derivatives of the ankle angular position data. The onset and offset of movement was defined as the first sample with velocity lager and smaller, respectively than 5% of the maximal acceleration. From this data, we computed the active range of motion (AROM), the angular velocity peak (Vp) and the movement smoothness (Sm). Sm was considered as the AROM between the onset and the first peak-velocity of movement (i.e., the first movement unit). For each variable, we computed the percentage of change between the first and last test.

	Mean	Minimal	Maximal
AROM	11.37	0.27	25.61
Vp	5.75	-5.98	14.97
Sm	18.39	-0.11	36.18
MVC DF	28.84	1.52	91.51

Table 2: Percentage of change between the first and the last test in kinematic and kinetic parameters.

3. Results and discussion

Preliminary results obtained on eight incomplete SCI patients are presented in Table 2. Globally, results show that all kinematic (i.e., AROM, Vp and Sm) and kinetic (i.e., MVC DF) parameters increased over 4 weeks of Lokomat training. These enhancements suggest a beneficial effect of the robot-assisted locomotor therapy on voluntary movement at the ankle joint in SCI patients. During the Lokomat training, the stretch of the ankle muscles could conducted to a diminution in spasticity in the gastrocnemius (GS) and reduce its reciprocal inhibitory effects on tibialis anterior (TA) activation. The enhancement of TA voluntary activity, which is observed through an increase in dorsiflexion MVC involved the TA, supports this hypothesis.

These finding have to be confirmed with an increase number of patients. Moreover, further investigations concerning muscular activation patterns between agonists and antagonists have to be conduct to get a better understanding of how recovery is driven by a therapy based on Lokomat.

References

[1] B. Ashworth. Preliminary trial of carisoprodol in multiples sclerosis. *Practitioner*, 192:540–542, 1964.

[2] H. Barbeau and S. Rossignol. Recovery of locomotion after chronic spinalization in the adult cat. *Brain Research*, 412(1):84–95, 1987.

[3] R. Bohannon. Reference values for the timed up and go test: a descriptive meta-analysis. *Journal of Geriatric Physical Therapy*, 29(2):64, 2006.

[4] P. Ditunno and J. Dittuno. Walking index for spinal cord injury (WISCI II): scale revision. *Spinal Cord*, 39(12):654–656, 2001.

[5] K. Gerhart, E. Bergstrom, S. Charlifue, R. Menter, and G. Whiteneck. Long-term spinal cord injury: functional changes over time. *Archives of Physical Medicine and Rehabilitation*, 74(10):1030–1034, 1993.

[6] T. Hornby, D. Zemon, and D. Campbell. Robotic-assisted, body-weight–supported treadmill training in individuals following motor incomplete spinal cord injury. *Physical Therapy*, 85(1):52, 2005.

[7] H. Lim, D. Lee, W. McKay, M. Priebe, S. Holmes, and A. Sherwood. Neurophysiological assessment of lower-limb voluntary control in incomplete spinal cord injury. *Spinal Cord*, 43(5):283–290, 2005.

[8] S. Mazzoleni, E. Boldrini, C. Laschi, M. Carrozza, G. Stampacchia, and B. Rossi. Changes on EMG activation in healthy subjects and incomplete SCI patients following a robot-assited locomotor training. In *IEEE International Conference on Rehabilitation Robotics*, 2011.

[9] M. M. Mirbagheri, L. L. Ness, C. Patel, K. Quiney, and W. Z. Rymer. The effects of robotic-assisted locomotor training on spasticity and volitional control. In *IEEE International Conference on Rehabilitation Robotics*, 2011.

[10] W. Rymer and R. Powers. Muscular weakness in incomplete spinal cord injury. *Comprehensive Therapy*, 13(7):3–7, 1987.

[11] C. Thomas, M. Tucker, and B. Bigland-Ritchie. Voluntary muscle weakness and co-activation after chronic cervical spinal cord injury. *Journal of Neurotrauma*, 15(2):149–161, 1998.

[12] A. Van Der Salm, A. Nene, D. Maxwell, P. Veltink, H. Hermens, and M. IJzerman. Gait impairments in a group of patients with incomplete spinal cord injury and their relevance regarding therapeutic approaches using functional electrical stimulation. *Artificial organs*, 29(1):8–14, 2005.

[13] H. van Hedel, M. Wirz, and V. Dietz. Assessing walking ability in subjects with spinal cord injury: validity and reliability of 3 walking tests. *Archives of Physical Medicine and Rehabilitation*, 86(2):190–196, 2005.

[14] M. Wirz, D. Zemon, R. Rupp, A. Scheel, G. Colombo, V. Dietz, and T. Hornby. Effectiveness of automated locomotor training in patients with chronic incomplete spinal cord injury: a multicenter trial. *Archives of Physical Medicine and Rehabilitation*, 86(4):672–680, 2005.

This research was supported by grants from the from the National Institutes of Health (NIH) and the Craig H. Neilsen Foundation.