

Effect of Robot-Assisted Treadmill Training on Motor Functions Depending on Severity of Impairment in Patients with Bilateral Spastic Cerebral Palsy

Stanislava Klobucká^{1,*}, Michal Kováč², Elena Žiaková^{1,3} and Robert Klobucký⁴

¹Rehabilitation Centre Harmony, Bratislava, Slovakia

²Clinic of Neurology, Faculty Hospital, Nové Zámky, Slovakia

³Slovak Medical University, Faculty of Nursing and Health Professional Studies, Bratislava, Slovakia

⁴Slovak Academy of Sciences, Institute for Sociology, Bratislava, Slovakia

Abstract: *Objective:* To assess impact of RATT (robot-assisted treadmill training) on motor function in patients with cerebral palsy depending on the severity of motor impairment.

Design: Uncontrolled prospective pilot study with pre-post treatment outcome comparison according to severity of motor impairment.

Setting: Outpatient Rehabilitation Centre.

Participants: Fifty-one patients aged 4 - 27 years with bilateral spastic cerebral palsy.

Interventions: Patients were divided into two groups according to severity of motor impairment determined by the Gross Motor Function Classification Scale (GMFCS). All 51 participants underwent 20 RATT sessions over a 5-6 week period in an outpatient approach using the Lokomat[®] driven gait orthosis (DGO).

Outcome Measures: Dimension A(lying, rolling), B(sitting), C(crawling, kneeling), D (standing) and E(walking, running, jumping) within the Gross Motor Function Measure (GMFM-88), 6-minute walking test, 10-meter walk test, Functional Ambulation Categories (FAC).

Results: Patients demonstrated statistically significant improvements in all GMFM-88 dimensions. Improvements in GMFM A, B and C were significantly larger in the more severely affected cohort (GMFCS III, IV) compared to the mildly affected cohort (GMFCS I, II). In contrast, GMFM D and E improvements were greater in the mildly affected cohort, but not statistically significant. Mean (SD) maximum gait speed of 0.75 (0.48) to 0.89 (0.52) m/s; mean (SD) 6 Min WT of 154 (103.21) to 191.21 (114.55) m; as well as the mean (SD) FAC of 1.44 (1.22) to 1.89 (1.33) showed a statistically significant level of improvement ($p = .000$).

Conclusion: RATT is a promising treatment option in ambulatory and non-ambulatory patients with cerebral palsy. The severity of motor impairment affects the amount of improvement that can be achieved.

Keywords: Robot-assisted treadmill training, cerebral palsy, gross motor function measure, impairment, neurodevelopmental concept.

CLINICAL MESSAGES

- This is the first study, to our knowledge, in which all GMFM-88 dimensions (A, B, C, D and E) were tested to evaluate robot-assisted treadmill training in contrast to other studies, where only dimension D (standing) and E (walking, running, jumping) are assessed within GMFM-66 range.
- After 4-5 week robot-assisted treadmill training using Lokomat[®], we recorded an objective improvement in motor function and functional gait parameters in mildly, as well as severely affected patients with bilateral spastic CP.

- The severity of motor impairment affects the amount of the achieved improvement.
- Measuring using the GMFM-88 range allowed us to obtain results supporting the neurodevelopmental hierarchical concept of postural ontogenesis applicable in gait pattern motor learning using robot-assisted treadmill training in the Lokomat[®] device.

Cerebral palsy (CP) continues to be a major medical and social issue. The complex issue of children with cerebral palsy requires a multidisciplinary approach involving cooperation between the neurologist, rehabilitation physician, physical therapist, orthopaedic surgeon, orthopaedic prosthetics, psychologist, speech therapist, phoniatrist, ophthalmologist and others, interlaced with social

*Address correspondence to this author at the Rehabilitation Centre Harmony, Kudlakova 2, 841 01 Bratislava, Slovak Republic; Tel: +421264287909; Fax: +421264287907; E-mail: stanislavaklobucka@gmail.com

assistance and special pedagogy. An early start to rehabilitation is of fundamental importance with therapeutic exercise forming a critical component thereof.

Ever increasing emphasis has been placed on an active approach to therapy, including intensive, repetitive, task-specific training to support neuroplasticity. Locomotor training has become an effective means of improving walking performance in patients with gait impairment. In the past decade there has been a striking increase in the use of robotic therapy, especially in patients with strokes, cerebrospinal trauma, and, last but not least, children with cerebral palsy. Based on the principle of motor learning, which describes the correlation between the repetition of activities and improvement in motor function, robot-assisted locomotor therapy using computer controlled electronic orthoses were developed in the late 1990s (University of Zurich, 1998).

The activation of supra-spinal and spinal central pattern generators, as described in animal experiments, supports the theoretical basis of this therapeutic concept [1-4].

Since higher brain centers are often damaged in children with cerebral palsy, it is assumed that central pattern generators activation and automatic reciprocal mechanisms play an important role in stimulating walking through locomotor training [3]. The existence of such spinal networks in humans is supported by the fact that the walking/stepping reflex is preserved in anencephalic newborns [5, 6], but conclusive evidence is still lacking.

An optimum amount of afferent impulses is essential to stimulate the locomotion centers in the spinal cord. This can be achieved by repeating movements of lower limbs in a rhythmic physiological pattern, which is also the key to the stimulation of motor plasticity.

According to the neuro developmental hierarchical concept we assume that a healthy child with an intact CNS integrates anti-gravity righting and preprogrammed phasic functions, which is a precondition for holding the head and trunk up righting a vertical position and subsequently leads to independent self-bipedal locomotion [7]. Phasic movement (muscle function), which manifests in the stepping reflex, is an integral part of walking. The ability

to maintain an upright posture is required in order to complete step movements. This implies that ontogenetic factors and straightening, which belong to the forward bipedal movement, are integral part of this movement. Straightening mechanisms in normal bipedal locomotion require an appropriate degree of maturity in the development of postural ontogenesis. The principle of forward movement as a prerequisite of intact motor development requires the harmonious development of postural reactivity with appropriate straightening mechanisms and corresponding phase mobility [8].

There are several basic approaches to walking rehabilitation:

- Conventional over-ground gait training (COGT)
- Manually assisted body-weight-supported treadmill training (BWSTT)
- Robot-assisted treadmill training (RATT).

Robot-assisted treadmill training in comparison with conventional over ground training offers constant and reproducible afferent input, precise control of the main parameters of gait, an increase in specific gait rehabilitation by a greater amount of stepping practice due to lower personal effort and costs, increased speed and longer walking distance during therapy sessions. Therapy is more efficient and this may be the principal advantage over conventional over ground training, conventional gait or treadmill training, which may have the same effect, but requires more effort and more therapists [9].

The effectiveness of robot-assisted locomotor therapy to improve walking ability has been demonstrated in adult patients with stroke, spinal cord injuries and traumatic brain injuries [10-15]. Preliminary studies suggest promising results when using Robot-assisted treadmill training in patients with other neurological diseases, for example multiple sclerosis [16, 17] and Parkinson's disease [18].

Since 2005 robot-assisted treadmill training has been used for paediatric patients with motor function disorders of various etiologies, most commonly in children with cerebral palsy. In non-randomized studies involving robot-assisted treadmill training in children with central gait impairment using the Lokomat[®] driven gait orthosis has been shown to contribute to improvements in motor function, speed and endurance in walking and walking stereotype [4, 5, 9, 13, 19].

To the author's knowledge, only dimensions D (standing) and E (walking, running, jumping) are assessed within the range of GMFM-66 in recent studies the gait training using DGO. However, we observed stabilization of axial muscle tone in our patients, which is reflected in improvements in sitting, crawling and rolling. Therefore, in order to objectify these observations, we decided to evaluate all GMFM-88 dimensions (A, B, C, D and E) for the patients in this study.

The aim of the present study was to assess and evaluate the feasibility of applying intensive task specific robot-assisted locomotor training using Lokomat[®], an electronically controlled driving gait orthosis, in outpatient rehabilitation in patients with movement disorders associated with cerebral palsy. We also attempted to document the effectiveness of Lokomat[®] robot-assisted locomotor therapy in its ability to influence motor functions and functional gait parameters in patients with cerebral palsy. We also evaluated the impact of robot-assisted treadmill training on motor function in patients with cerebral palsy based on the severity of motor impairment.

METHODS

Participants

The study was conducted at the Harmony Rehabilitation Centre at Kudláková 2, Bratislava from March 2008 to September 2011. 51 patients (28 males 54.9% and 23 females 45.1%) with bilateral spastic cerebral palsy (mean age 10 y 6 mo SD 5.6, range 4 y 3 mo – 27 y) underwent 20 sessions of robot-assisted treadmill training in an outpatient approach using the Lokomat[®] DGO. The adult module was used for 12 patients and the paediatric module for 39 patients.

The severity of motor impairment was determined using the GMFCS classification system (20). GMFCS level I and II patients (n= 13, 25.5%) were classified as mildly impaired. GMFCS III and IV patients were classified as moderate to severely affected (n= 38, 74.5%) (Table 1).

Inclusion criteria were the diagnosis of bilateral cerebral palsy by a paediatric neurologist pursuant to ICD 10th revision. As the paediatric orthosis is suitable for femur length of 21 to 35 cm, femur length had to be at least 21 cm, which correlates with an age of about four years. Patients had to cooperate and had to be able to signal fear, pain or discomfort during therapy.

Table 1: Clinical Characteristics of the 51 Participants

Mean (SD) age (years)	10 y 6 mo (5.6)
Wheelchair	7
Walking aids (n)	
Walker	10
None	15
Male	28(54.9%)
IV	15 (29.4%)
III	23 (45.1%)
II	11(21.6%)
I	2 (3.9%)
GMFCS level (n)	
Gender	
Female	23(45.1%)
Driven gait orthosis type (n)	
Crutches	19
Child module	39
Adult module	12

Exclusion criteria included any changes in concomitant treatment in the 3 months before the study (additional treatment with botulinum toxin, orthopaedic surgery or dorsal rhizotomy 12 weeks prior to the study).

Exclusion criteria have been established previously [9] and consist of severe lower extremity contractures, fractures, osseous instabilities, osteoporosis, severe retarded bone growth, unhealed skin lesions in the lower extremities, thromboembolic diseases, cardiovascular instability, acute or progressive neurological disorders and aggressive or self-harming behavior and contraindication to full-body load due to prior surgeries.

The study was approved by local ethics committees of and complied with the guidelines set forth in the Declaration of Helsinki (1964).

Written informed consent was obtained from each patient's parents or guardians and the patients themselves when applicable.

Device

Lokomat[®] represents a modern medical device which replaces manually assisted gait training on a treadmill, either in part or in full. It is a driven gait

orthosis (DGO) controlled by a PC that automates locomotion therapy on a treadmill. It consists of a moving walkway (treadmill), a patented suspension system and electronically controlled orthosis. The electromechanical body-weight support system monitors and adjusts the weight support system in real time to maintain body-weight support at the prescribed level. This body-weight support system contrasts with the stiff, counterweighted support system used in original Lokomat[®] model. Movable parts are controlled by three computers and specialized software. The knee and hip joints are controlled by position and force sensors, which allow for individual adjustments [15]. Patients' legs are guided using a pre-programmed physiological gait pattern. As the parameters of each training session, including step counts, speed, body weight support, guidance force and total distance, are well defined and continuously logged, gait training allows for easy comparisons between individuals and even different training settings [13] (Figure 1).



Figure 1: Robot-assisted treadmill training using the Lokomat[®] system.

An important element in therapy is dynamic fixation of the pelvis using braces and the adjustable pelvic restraint, which allows the physiological position of the ideal walking stereotype to be achieved. Dorsal flexion of the ankle joint is achieved by using passive foot clamping (foot lifter). Patients and therapists can monitor and influence the process of training in real time. Software enabling training in a virtual

environment has been developed in order to increase the motivation of the paediatric patients. This allows patients to move through different types of virtual environments and complete various exercises during treatment, which increases the probability of actively engaging patients in the therapeutic process.

Intervention

Robot-assisted treadmill training using the Lokomat[®] system was the essential (primary) therapeutic intervention for patients participating in this study. All of the patients stopped their usual physiotherapy.

As no guidelines regarding robot-assisted treadmill training for patients with cerebral palsy had been previously established, we defined the period of therapy and the frequency of therapy sessions using experience and knowledge gathered from previously completed studies and also with regard to the individual capacities and limits of patients and their parents.

Patients received 20 therapeutic units during the 5-6 week period at a frequency of 3-5 times a week. One session lasted for 55-60 minutes. This resulted in 30 minutes of real walking time as mounting, dismounting and adjusting patients in the device took approximately 20-25 minutes of each session. Training speed ranged from 1.1 m/s for severely impaired patients to 1.8 m/s for the mildly impaired group.

Outcome Measurements

Baselines measurements were conducted 1-2 days before the trial began and outcome measurements were evaluated after completion of the intervention.

The more detailed 88 itemized version GMFM was applied in this study to evaluate motor functions; this version assesses motor skills in five dimensions: A- laying, rolling, 17 items, B- sitting, 20 items, C- crawling, kneeling, 14 items, D – standing, 13 items, E- walking, running, jumping, 24 items [21, 22]. Gait speed was assessed with a 10-meter walking test (10 mWT). We recorded the time needed to cope with a distance of 10 m [23, 24]. To evaluate gait endurance, a 6-minute walking test was performed. We recorded total covered distance over 6 minutes [24]. Functional Ambulation Categories (FACs) were used to determine the amount of assistance the child required during walking. These categories include 6 levels of support needed when walking from level 0, when the patient is unable to walk and needs assistance of two or more

persons to level 5, which means independent walking [25]. Patients wore their usual footwear and utilized their regular walking aids during the evaluation of gait speed and endurance. Patients were instructed to walk at a comfortable speed. The Lokomat® system was used to record training time (minutes), walking distance (m) and mean walking velocity (m/s) from each session.

Statistical Analyses

Data was processed using MS Office Excel 2007 and SPSS 16.0 for Windows. Data files in our case were tested for normality using the Kolmogorov-Smirnov test of normality. Non-parametric test procedures were used as the data in our study was not normally distributed. Differences between pre- and post-training were analyzed using the non-parametric Wilcoxon signed rank test for paired samples. Differences in outcomes between the two groups depending on severity of impairment were analyzed using the Mann-Whitney test for unpaired samples. Two-tailed significance was stated at $p < 0.05$ and highly statistically significant if $p < 0.001$.

RESULTS

Evaluation of the Improvement of Motor Function and Functional Gait Parameters

Fifty- one patients with bilateral spastic cerebral palsy underwent 20 robot-assisted treadmill training

sessions with a frequency 3-5 times a week over a 5-6 week period using the Lokomat® driven gait orthosis. The mean duration of one therapeutic unit (T.U.) was 30.21 min (SD 4.90, range 20.39 – 39.36 min) and the mean walking distance per session (during a single T.U.) was 649.79 m (SD 187.35, range 131-975m). The mean total distance walked by a patient during the trial from 20 T.U. was 13,197.43 m (SD 3,889.54, range 2,481 – 19,502) and the mean of total time walked by a patient was 615.66 min (SD 108.65, range 392.24 – 879.04).

The assessed outcome parameters improved in the study group as follows:

Significant improvement was noted for the **A dimension (lying, rolling)** from mean (SD) 76.16% (17.27%) to 86.04% (13.65%); $Z = -5.779$; $p = 0.000$, representing an improvement of 9.88%.

In category **B (sitting)** we recorded the significant increase of 10.67% from mean (SD) 60.58% (29.03%) to 71.25% (27.37%); $Z = -6.93$; $p = 0.000$.

The sum score of **crawling, kneeling section (C)** of GMFM increased significantly by 9.02% from mean 57.59% (29.86%) to 66.61% (30.03%); $Z = -6.247$; $p = 0.000$. The scores of the standing section (D) of the GMFM increased significantly by 8.29% from mean (SD) 31.82 % (29.73%) to 40.11% (32.54%); $Z = -6.247$; $p = 0.000$.

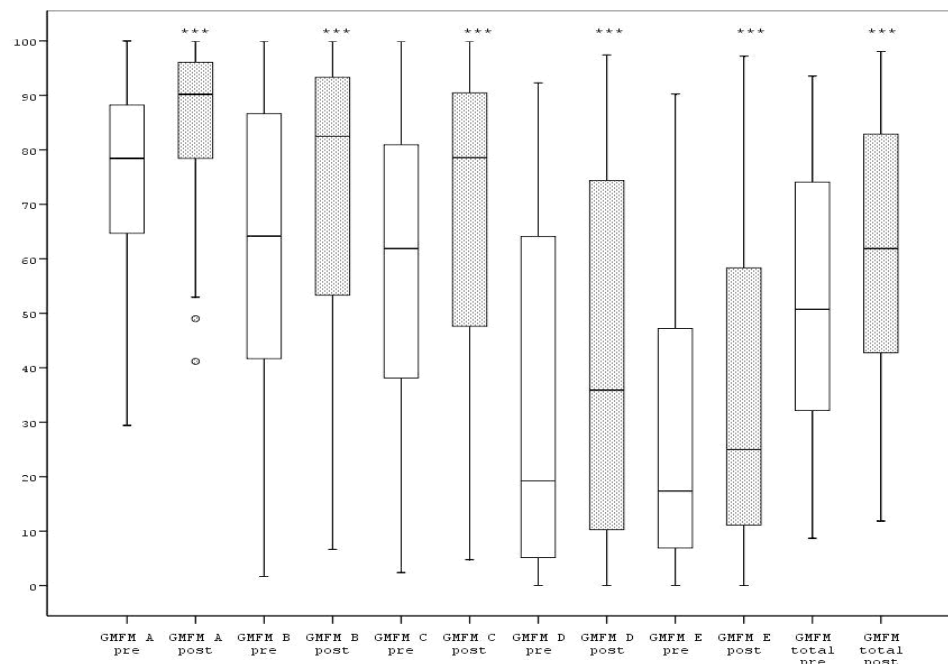


Figure 2: Box plots showing the distribution and improvement after the therapy in dimensions A, B, C, D and E of the GMFM-88 score. ($p < 0.001$).

The **walking section (E)** showed a significant improvement of 7.32% from mean (SD) 28.27% (26.35%) to 35.58% (29.13%); $Z = -6.326$; $p = 0.000$. Totally (**total GMFM**) we recorded improvement at 9.05% from mean (SD) 50.90% (24.33%) to 59.95% (24.24%); $Z = -7.001$; $p = 0.000$. Patients demonstrated statistically highly significant improvement in all the dimensions of the GMFM-88 after completing 20 sessions (Figure 2).

The mean (SD) maximum **gait speed** evaluated 10 meter walking test (10 mWT) in tested 19 patients also showed statistically significant level of improvement from 0.75 (0.48) to 0.89 (0.52) m/s; $Z = -3.825$; $p = 0.000$. It means improvement of 18.66 %.

The mean (SD) **covered distance** in 6 minute walking test (6 min WT) increased significantly by 24.16 % from 154 (103.21) to 191.21 (114.55) m; $Z = -3.824$; $p = 0.000$.

The mean (SD) score of the **Functional Ambulation Categories (FAC)** as a measure of the amount of necessary walking assistance increased significantly by 31.25 % from 1.44 (1.22) to 1.89 (1.33) ($Z = -4.684$; $p = 0.000$).

Evaluation of Improvement in Motor Functions Dependent on Severity of Motor Impairment

Patients with GMFCS levels I, II ($n = 13$, 25.5 %, cohort 1) were classified as mildly impaired, whereas patients with GMFCS levels III, IV were classified as

moderately to severely affected ($n = 38$, 74.5%, cohort 2).

The improvements in GMFM A, B and C were significantly greater in the more severely affected cohort 2 (GMFCS III, IV) compared to the mildly affected cohort 1 (GMFCS I, II). By contrast, improvements in GMFM D and E were significantly greater in the mildly affected cohort, but this gain did not achieve statistical significance.

In GMFM **A (lying, rolling)**, a mean (SD) improvement of 9.88 % (8.92) was noted. There was a statistically significant difference in improvement in cohort 2 (mean rank 29.39%) in comparison with cohort 1 (16.08%). $Z = -2.799$, $p = 0.005$

In category **B (sitting)**, we recorded a mean (SD) increase of 10.67% (7.56). Cohort 2 (mean rank 29.30%) had a statistically significant difference in improvement over cohort 1 (mean rank 16.35%), $Z = -2.719$, $p = 0.029$.

The sum score of the **crawling, kneeling section (C)** of GMFM increased by a mean (SD) of 9.02% (8.30). In cohort 2 (mean rank 28.64%) there was a statistically significant difference in improvement in comparison with cohort 1 (mean rank 18.27 %), $Z = -2.184$, $p = 0.029$.

The scores of the **standing section (D)** of the GMFM increased by a mean (SD) of 8.29% (8.29).

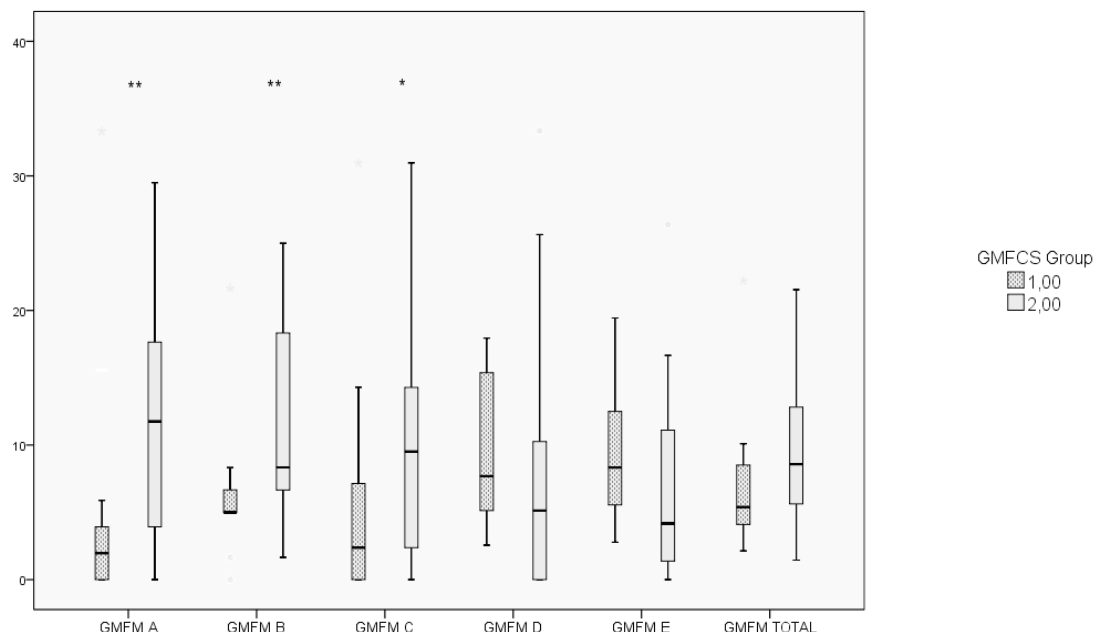


Figure 3: Box plots showing the improvement in outcome measurements stratified to the severity of motor impairment (* $p < 0.05$, ** $p < 0.01$).

Here we noted a difference in favour of the improvement in cohort 1 (mean rank 30.62%) compared with cohort 2 (mean rank 24.42%), but it was not statistically significant. $Z = -1.307$, $p = 0.191$.

The **walking section E** showed a mean improvement (SD) of 7.32 % (5.99). We saw a significant improvement in favour of the less (mildly) affected patients (cohort 1, mean rank 31.92%, cohort 2, mean rank 23.24%), but this was not statistically significant. $Z = -1.854$, $p = 0.064$.

Having summed up the values of each category of GMFM, we arrived at a mean (SD) improvement of 9.05 (5.51) in the **total GMFM**. Overall, we saw a significant improvement in cohort 2 (mean rank 27.92%) over cohort 1 (mean rank 20.38%), but this was below statistical significance. $Z = -1.578$, $p = 0.115$ (Figure 3).

DISCUSSION

The aim of this prospective study was to determine the effect of robot-assisted treadmill training using the Lokomat® system on motor functions and functional gait parameters after task-specific locomotor training in children, adolescents and adults with cerebral palsy. We also attempted to assess the possibility of affecting motor function using robot-assisted treadmill training depending on the severity of impairment.

We are aware of a few limitations in this study. The first is the fact that this was not a randomized, placebo-controlled study. Children in the study were heterogeneous with respect to age and severity of impairment. This does, however, reflect a normal population at a paediatric neurological rehabilitation clinic.

No control group was included and outcome assessors were not blinded to pre- and post-training conditions. The study attempted to perform assessments with identical examiners; this could not be achieved in all cases due to organizational reasons.

We also cannot exclude the impact of natural continuation in the ongoing development on results. However, there is evidence that no significant changes occur in the natural course of GMFM D and E scores in children and adolescents with cerebral palsy over an observation period of three to six weeks without intervention [26-28].

Several studies investigated the sustainability of achieved motor improvements following robot-assisted

treadmill training or body weight supported treadmill training. Published studies show that results persist for at least a 4 month period [9, 26, 31, 32, 38, 39].

An important factor of the success of therapy is patient cooperation and active participation. As stated by Koenig *et al.* [40] and as we observed during this study, implementation of control strategies and an adapted biofeedback system for children is an important factor in obtaining maximum participation, in particular among paediatric patients; integrated technology helps to facilitate this process by enabling walking in a virtual reality environment.

Improvement in the final measurements presented in our study was consistent with the information provided by patients, parents and caregivers. They reported increased endurance, an improved ability to walk upstairs and improved overall mobility in children and adolescents after therapy with the Lokomat® system during activities of daily living in different positions (sitting, standing and laying down). An increased ability to assist during transfers, either using crutches, walkers, with the assistance of another person, or in other ways was observed as well. No adverse side effects were reported.

Proper management of cerebral palsy treatment is the only prophylaxis for the complications arising from structural defects (such as pain, secondary musculoskeletal problems, possible dysfunction of internal organs, orthopaedic, prosthetic and surgical intervention with mandatory hospitalization or subsequent spa treatment), which ultimately allows for a significant reduction in costs for subsequent medical care.

Improvement of Motor Function and Functional Gait Parameters

After completing 20 robot-assisted treadmill training sessions, we have documented significant improvement in outcome parameters -GMFM A, B, C, D, E, total, Functional Ambulation Categories (FAC), walking speed, and endurance when walking.

Improvement in walking stereotype and its functional parameters (dimension E in GMFM, 10 meter walking test, 6 minute walking test) fits into the concept of task specific motor learning. Similar results were documented by Meyer-Heim *et al.* [9, 13] and by Borggraefe *et al.* [4, 19] in their studies, which tested dimension D and E, walking speed, and walking endurance after completing robot-assisted locomotor

training using the Lokomat[®] in children and adolescents suffering from CP. Most authors dealing with gait training evaluate these parameters. However, we noticed a significant improvement in dimensions A, B and C in GMFM. We have documented significant improvement in stabilization of axial muscle tone, as reflected in improved motor function and stability when sitting and standing. This suggests additional effects on the stabilization of posture beyond task specific improvement of walking parameters and the potential role of robot-assisted treadmill training in non-ambulatory children with cerebral palsy.

The original intent and purpose of robot-assisted treadmill training was to improve locomotor functions and walking stereotype, which would support the theory of motor learning; we also registered a significant improvement in axial muscle tone and flexor group relaxation in the lower extremities. Agonist-antagonist muscle co/activation within developmental kinesiology is a possible explanation [7].

The magnitude of a GMFM score change considered to be clinically significant is of question. A 6% change in the total score or within a dimension of the GMFM is considered to be clinically significant in children with cerebral palsy (21). Wang and Yang (29) stated in their study on responsiveness of the GMFM that an increase of 3.71% would be clinically meaningful.

The first experiment in paediatric neurological rehabilitation with the aim of determining the feasibility of robot-assisted treadmill training in children with central gait impairment was the Meyer-Heim *et al.* study [9]. A total of 24 children (age 5-19 y) completed the training, representing 19 therapeutic units for the in-patient and 12 therapeutic units for the outpatient group.

Meyer-Heim *et al.* in the next study (13) presented results of a 3-5 week period of driven gait orthosis training with a frequency of 3-5 sessions per week. A total of 22 children with cerebral palsy (age 4-11 y) and GMFCS level II to IV underwent locomotor training using the Lokomat[®] system. The mean number of therapeutic units was 15.1. The duration of one therapeutic unit averaged 31.5 min.

In our study, patients have improved very similarly to in-patient children with 19 therapeutic units in the Meyer- Heimstudy [9]. We registered an improvement in the D dimension on average of 8.29% (almost the

same as the Meyer-Heim *et al.* [9] with an improvement of 8.7 %, in the D dimension) and in the E dimension by an average of 7.32 %, which is another statistically significant increase, after 20 therapeutic units. Walking speed after completion of therapy in our study was comparable with Meyer-Heim *et al.* [13] which recorded an increase in walking speed from 0.78 to 0.91m/s). In our case, this meant a statistically significant level ($p=0.000$) of improvement from 0.75 to 0.89 m/s. We also documented a comparable improvement in 6 minute walking test as the covered distance increased significantly from 154 to 191.21 m. The increase in distance when walking in 6 minute walking test from the Meyer- Heim *et al.* study [9] was an average of 151.5 to 251.3 m.

Borggraefe *et al.* [4] a presents results after completing 12 therapeutic units of robot-assisted locomotor therapy using the Lokomat[®] system in 20 cerebral palsy patients (age 4-20 y). Significant improvement was observed in the D dimension of GMFM-66 of 5.9% and the E dimension of 5.3%.

Walking speed is another important criterion in deciding whether gait will be the functional way of locomotion in children with cerebral palsy. This often limits the ability of the child to be active in the community and interact with peers. Changes in walking speed could have a major impact on a child's independent mobility, especially over shorter distances, such as walking around the house or moving between classes at school. Such an increase in walking speed and walking endurance was also recorded by Patriitti *et al.* [30] and Montinaro *et al.* [31] in their work. Montinaro *et al.* [31] also compared the results of therapy using the Lokomat[®] system with conventional physiotherapy. The values show a trend of superiority of Lokomat[®] therapy in improving gait parameters.

Improvement of Motor Functions Depending on the Severity of Motor Impairment

The results of our study indicate significantly greater improvements in the GMFM A, B, and C dimensions in the more severely affected cohort 2 (GMFCS III, IV) compared to the mildly affected cohort 1 (GMFCS I, II). In contrast, improvements in the GMFM D and E were greater in the mildly affected cohort.

The results of research studies dealing with effects of body weight supported treadmill training on gross motor function and gait in children with cerebral palsy suggest that body weight supported treadmill training

may have a beneficial effect on the functions associated with the ability to walk, especially endurance [23, 26, 27, 32, 33]. Children in all these studies with the initial higher GMFCS levels (I, II) showed positive changes in gross motor functions, which was due mainly to a better ability to walk.

Severely affected children (GMFCS III, IV) showed reduced dependence on caregivers, an increased ability to assist during transfers, as well as weight acceptance in the lower extremities after treatment and improved walking ability when supported in the harness [34].

Borggraefe *et al.* [4] study showed improvements in GMFM D and E that were significantly greater in the mildly affected group of patients (GMFCS I, II) compared to the more severely affected cohort (GMFCS III, IV) after completing 12 sessions of robot-assisted locomotor therapy using the Lokomat[®] system. Patients with moderate to severe disabilities achieve less improvement compared to mildly affected patients.

This is consistent with recent findings that cerebral palsy patients with GMFCS levels of III and IV show a lower potential to gain motor function over time compared to mildly affected patients using GMFM developmental curves [35, 36].

Similar results were also recorded in the case study (36), which described outcomes of gait training intervention in four children (5-8 y) with cerebral palsy using a robot-driven gait orthosis (Paediatric Lokomat[®]).

Participants were paired based on functional abilities (Gross Motor Function Classification System, GMFCS). Two patients were GMFCS III and the other two patients were classified as GMFCS II. All four patients completed a 6-week robot-assisted treadmill training intervention involving a 30-minute therapy unit with a frequency of 3 times a week. GMFM Dimensions D and E, walking speed (10 meter walking test) and walking endurance in 6 minute walking test were evaluated. Clinical gait analysis was also performed using a Vicon 512 device, which assesses changes in the gait mechanism. As in our study, all patients showed an improvement in locomotor functions. The lower functioning children (GMFCS III) showed larger improvements in standing function, but few changes in gait mechanics. Conversely, the higher functioning children (GMFCS II) showed an improvement in gait mechanism, including an increased step length, greater peak hip extension, greater peak knee extension and

smaller ankle dorsiflexion in stance. These changes led to an easier and freer walking stereotype in children.

CONCLUSION

After 4-5 weeks of robot-assisted treadmill training using the Lokomat[®], we recorded an objective improvement in functional gait parameters and motor functions in mildly, as well as severely affected patients with bilateral spastic cerebral palsy. These improvements correlated well with the final GMFM score in all dimensions. Stabilization of the trunk muscles preceding an improvement in standing and gait parameters indicates the validity of the neuro developmental hierarchical concept, based on the postural ontogenesis of the child [8]. Improvements in GMFM A, B and C were significantly greater in the more severely affected cohort (GMFCS III, IV) compared to the mildly affected cohort (GMFCS I, II). In contrast, improvements in the GMFM D and E were greater in the mildly affected cohort, but this increase didn't achieve statistical significance. The severity of motor impairment does influence the amount of progress and achievement that can be made [4].

Robot-assisted treadmill training appears to be safe and easily adaptable to outpatient treatment of ambulatory and non-ambulatory patients without any undesirable side effects [4, 39].

Driven gait orthosis training was successfully integrated into a rehabilitation program for children, adolescents and adults with cerebral palsy as an option to increase participation in motor activity and results show improvement in locomotion functions.

COMPETING INTERESTS

None.

ACKNOWLEDGEMENTS

We are grateful to director of Rehabilitation Centre Harmony Alojz Halas for support and willingness to help in making this work. We express our gratitude to the children and their families participating in this study. We also thank the staff of the RC Harmony for their contribution to this work. We thank to John Malcovsky and Miroslav Ziak for language review.

ABBREVIATIONS

RATT = Robot-assisted treadmill training

GMFCS = Gross motor function classification scale

CPG	=	Central pattern generator
DGO	=	Driven gait orthosis
BWSTT	=	Body weight supported treadmill training
SCI	=	Spinal Cord Injuries
TBI	=	Traumatic Brain Injuries
MS	=	Multiple Sclerosis
ICD	=	International Classification of Diseases
FAC	=	Functional Ambulation Categories
10 m WT	=	10 meter walking test
6 min WT	=	6 minute walking test

REFERENCES

- [1] Cazalets JR, Borde M, Clarac F. Localization and Organization of the Central Pattern Generator for Hind limb Locomotion in Newborn Rat. *J Neurosci* 1995; 15: 4943-51.
- [2] Duysens J, Van de Crommert H. Neural control of locomotion, Part 1: The central pattern generator from cats to humans. *Gait Posture* 1998; 7: 131-41.
[http://dx.doi.org/10.1016/S0966-6362\(97\)00042-8](http://dx.doi.org/10.1016/S0966-6362(97)00042-8)
- [3] Mac Kay-Lyons M. Central pattern generation of locomotion: a review of evidence. *Phys Ther* 2002; 82: 69-83.
- [4] Borggraefe I, Schaefer JS, Klaiber M, Dabrowski E, et al. Robotic- assisted treadmill therapy improves walking and standing performance in children and adolescents with cerebral palsy. *Eur J Pediatr Neurol* 2010; 14: 496-502.
<http://dx.doi.org/10.1016/j.ejpn.2010.01.002>
- [5] Borggraefe I, Meyer-Heim A, Kumar A, Schaefer JS, Berweck S, Heinen F. Improved gait parameters after robotic- assisted locomotor treadmill therapy in a 6-year-old child with cerebral palsy. *Movement Disord* 2008; 23: 280-3.
<http://dx.doi.org/10.1002/mds.21802>
- [6] Dietz V, Müller R, Colombo G. Locomotor activity in spinal man: significance of afferent input from joint and load receptors. *Brain* 2002; 125: 2626-34.
<http://dx.doi.org/10.1093/brain/awf273>
- [7] Kokavec M, Žiaková E. Developmental dysplasia of the hip. Diagnosis and treatment based upon the developmental kinesiology principles. Bratislava: Herba 2008.
- [8] Vojta V. Die zerebralen Bewegungsstörungen im Säuglingsalter, Ferdinand Enke Verlag, Stuttgart 1988.
- [9] Meyer-Heim A, Borggraefe I, Ammann-Reiffer C, et al. Feasibility of robotic assisted locomotor training in children with central gait impairment. *Dev Med Child Neurol* 2007; 49: 900-6.
<http://dx.doi.org/10.1111/j.1469-8749.2007.00900.x>
- [10] Mayr A, Kofler M, Quirbach E, Matzak H, Fröhlich K, Saltuari L. Prospective, blinded, randomized crossover study of gait rehabilitation in stroke patients using the lokomat gait orthosis. *Neurorehabil Neural Repair* 2007; 21: 307-14.
<http://dx.doi.org/10.1177/1545968307300697>
- [11] Wirtz M, Zemon DH, Rupp R, et al. Effectiveness of automated locomotor training in patients with chronic incomplete spinal cord injury: a multicenter trial. *Arch Phys Med Rehabil* 2005; 86: 672-80.
<http://dx.doi.org/10.1016/j.apmr.2004.08.004>
- [12] Hornby TG, Zemon DH, Campbell D. Robotic assisted, body-weight-supported treadmill training in individuals following motor incomplete spinal cord injury. *Phys Ther* 2005; 85: 52-66.
- [13] Meyer-Heim A, Ammann-Reiffer C, Schmartz A, et al. Improvement of walking abilities after robotic- assisted locomotion training in children with cerebral palsy. *Arch Dis Child* 2009; 94: 615-20.
<http://dx.doi.org/10.1136/adc.2008.145458>
- [14] Westlake KP, Patten C. Pilot study of Lokomat versus manual-assisted treadmill training for locomotor recovery post-stroke. *J Neuroeng Rehabil* 2009; 6: 1.
<http://dx.doi.org/10.1186/1743-0003-6-18>
- [15] Husemann B, Müller F, Krewer C, Heller S, Koenig E. Effects of locomotion training with assistance of robot-driven gait orthosis in hemiparetic patients after stroke. *Stroke* 2007; 38: 349-54.
<http://dx.doi.org/10.1161/01.STR.0000254607.48765.cb>
- [16] Beer S, Aschbacher B, Manoglou D, Gamper E, Kool J, Kesselring J. Robot-assisted gait training in multiple sclerosis: a pilot randomized trial. *Mult Scler* 2008; 14: 231-6.
<http://dx.doi.org/10.1177/1352458507082358>
- [17] Lo AC, Triche EW. Improving gait in multiple sclerosis using robot-assisted, body weight supported treadmill training. *Neurorehabil Neural Repair* 2008; 22: 661-71.
<http://dx.doi.org/10.1177/1545968308318473>
- [18] Ustinova K, Chernikova L, Bilimenko A, Telenkov A, Epstein N. Effect of robotic locomotor training in an individual with Parkinson's disease: a case report. *Disabil Rehabil Assist Technol* 2011; 6: 77-85.
<http://dx.doi.org/10.3109/17483107.2010.507856>
- [19] Borggraefe I, Kiwull L, Schaefer JS, Koerte I, et al. Sustainability of motor performance after robotic-assisted treadmill therapy in children: an open, non randomized baseline- treatment study. *Eur J Phys Rehabil Med* 2010; 46: 125-31.
- [20] Palisano R, Rosenbaum P, Walter S, Russell D, Wood E, Galuppi B. Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Dev Med Child Neurol* 1997; 39: 214-23.
<http://dx.doi.org/10.1111/j.1469-8749.1997.tb07414.x>
- [21] Russell DJ, Rosenbaum PL, Cadman DT, et al. The gross motor function measure: A means to evaluate the effects of physical therapy. *Dev Med Child Neurol* 1989; 31: 341-52.
<http://dx.doi.org/10.1111/j.1469-8749.1989.tb04003.x>
- [22] Russell DJ, Rosenbaum PL, Avery LM, Lane M. Gross Motor Function Measure (GMFM-66 & GMFM-88) User's Manual. Clinics in Developmental Medicine No. 159. London: Mac Keith Press 2002.
- [23] Provost B, Dieruf K, Burtner PA, et al. Endurance and gait in children with cerebral palsy after intensive body weight – supported treadmill training. *Pediatr Phys Ther* 2007; 19: 2-10.
<http://dx.doi.org/10.1097/01.pcp.0000249418.25913.a3>
- [24] Thompson P, Beath T, Bell J, et al. Test-retest reliability of the 10-metre fast walk test and 6-minute walk test in ambulatory school-aged children with cerebral palsy. *Dev Med Child Neurol* 2008; 50: 370-6.
<http://dx.doi.org/10.1111/j.1469-8749.2008.02048.x>
- [25] Holden MK, Gill KM, Magliozzi MR, et al. Clinical gait assessment in the neurologically: reliability and meaningfulness. *Phys Ther* 1984; 64: 35-40.
- [26] Schindl MR, Forstner C, Kern H, Hesse S. Treadmill training with partial body weight support in nonambulatory patients with cerebral palsy. *Arch Phys Med Rehabil* 2000; 81: 301-6.
[http://dx.doi.org/10.1016/S0003-9993\(00\)90075-3](http://dx.doi.org/10.1016/S0003-9993(00)90075-3)
- [27] Cherng RJ, Liu CF, Lau TW, Hong RB. Effect of treadmill training with body weight support on gait and gross motor

- function in children with spastic cerebral palsy. *Am J Phys Med Rehabil* 2007; 86: 548-55.
<http://dx.doi.org/10.1097/PHM.0b013e31806dc302>
- [28] Knox V, Evans, AL. Evaluation of the functional effects of a course of Bobath therapy in children with cerebral palsy: a preliminary study. *Dev Med Child Neurol* 2002; 44: 447-60.
<http://dx.doi.org/10.1111/j.1469-8749.2002.tb00306.x>
- [29] Wang H, Yang Y. Evaluation the responsiveness of 2 versions of the gross motor function measure for children with cerebral palsy. *Arch Phys Med Rehabil* 2006; 87: 51-6.
<http://dx.doi.org/10.1016/j.apmr.2005.08.117>
- [30] Patritti B, Sicari M, Deming M. Enhancement and retention of locomotor function in children with cerebral palsy after robotic gait training. *Gait Posture* 2011; 30: S9-S10.
<http://dx.doi.org/10.1016/j.gaitpost.2009.08.017>
- [31] Montinaro A, Piccinini L, Romei M, *et al.* Robotic-assisted locomotion training in children affected by cerebral palsy. *Gait Posture* 2011; 33: S55-S56.
<http://dx.doi.org/10.1016/j.gaitpost.2010.10.068>
- [32] Day JA, Fox EJ, Lowe J, Swales HB, Behrman AL. Locomotor training with partial body weight support on a treadmill in a nonambulatory child with spastic tetraplegic cerebral palsy: a case report. *Pediatr Phys Ther* 2004; 16: 106-13.
<http://dx.doi.org/10.1097/01.PEP.0000127569.83372.C8>
- [33] Begnoche DM, Pitetti KH. Effects of traditional treatment and partial body weight treadmill training on the motor skills of children with spastic cerebral palsy: a pilot study. *Pediatr Phys Ther* 2007; 19: 11-9.
<http://dx.doi.org/10.1097/01.pep.0000250023.06672.b6>
- [34] Mattern-Baxter K. Effects of partial body weight supported treadmill training on children with cerebral palsy. *Pediatr Phys Ther* 2009; 21: 12-22.
<http://dx.doi.org/10.1097/PEP.0b013e318196ef42>
- [35] Hanna SE, Bartlett DJ, Rivard LM, Russel DJ. Reference curves for the gross motor function measure: percentiles for clinical description and tracking over time among children with cerebral palsy. *Phys Ther* 2008; 88: 596-607.
<http://dx.doi.org/10.2522/ptj.20070314>
- [36] Beckung E, Carlsson G, Carlsdotter S, Uvebrant P. The natural history of gross motor development in children with cerebral palsy aged 1 to 15 years. *Dev Med Child Neurol* 2007; 49: 751-6.
<http://dx.doi.org/10.1111/j.1469-8749.2007.00751.x>
- [37] Sicari M, Patritti B, Deming LC, *et al.* Robotic gait training in children with cerebral palsy: A case series. *Gait Posture* 2011; 30: S2.
<http://dx.doi.org/10.1016/j.gaitpost.2009.07.077>
- [38] Dodd KJ, Foley S. Partial body-weight-supported treadmill training can improve walking in children with cerebral palsy: a clinical controlled trial. *Dev Med Child Neurol* 2007; 49: 101-5.
<http://dx.doi.org/10.1111/j.1469-8749.2007.00101.x>
- [39] Borggraeve I, Klaiber M, Schuler T, Warken B, *et al.* Safety of robotic- assisted treadmill therapy in children and adolescents with gait impairment: a bi-centre survey. *Dev Neurorehabil* 2010; 13: 114-9.
<http://dx.doi.org/10.3109/17518420903321767>
- [40] Koenig A, Brüttsch K, Zimmerli L, Guidali M, Duschau-Wicke A. Virtual environments increase participation of children with cerebral palsy in robot-aided treadmill training. *Virtual Rehabil* 2008; 121-6.

Received on 18-11-2013

Accepted on 13-12-2013

Published on 31-01-2014

DOI: <http://dx.doi.org/10.12970/2308-8354.2013.01.02.1>© 2013 Klobucká *et al.*; Licensee Synergy Publishers.

This is an open access article licensed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0/>) which permits unrestricted, non-commercial use, distribution and reproduction in any medium, provided the work is properly cited.