Effectiveness of Automated Locomotor Training in Patients With Chronic Incomplete Spinal Cord Injury: A Multicenter Trial

Markus Wirz, PT, David H. Zemon, MSPT, Ruediger Rupp, PhD, Anke Scheel, PT, Gery Colombo, PhD, Volker Dietz, MD, T. George Hornby, PT, PhD


Objective: To determine whether automated locomotor training with a driven-gait orthosis (DGO) can increase functional mobility in people with chronic, motor incomplete spinal cord injury (SCI).

Design: Repeated assessment of the same patients or single-case experimental A-B design.

Setting: Research units of rehabilitation hospitals in Chicago; Heidelberg, Germany; and Basel and Zurich, Switzerland.

Participants: Twenty patients with a chronic (>2y postinjury), motor incomplete SCI, classified by the American Spinal Injury Association (ASIA) Impairment Scale with ASIA grades C (n=9) and D (n=11) injury. Most patients (n=16) were ambulatory before locomotor training.

Intervention: Locomotor training was provided using robotic-assisted, body-weight-supported treadmill training 3 to 5 times a week over 8 weeks. Single training sessions lasted up to 45 minutes of total walking time, with gait speed between .42 and .69m/s and body-weight unloading as low as possible (mean ± standard deviation, 37%±17%).

Main Outcome Measures: Primary outcome measures included the 10-meter walk test, the 6-minute walk test, the Timed Up & Go test, and the Walking Index for Spinal Cord Injury–II tests. Secondary measures included lower-extremity motor scores and spastic motor behaviors to assess their potential contribution to changes in locomotor function. All subjects were tested before, during, and after training.

Results: Locomotor training using the DGO resulted in significant improvements in the subjects’ gait velocity, endurance, and performance of functional tasks. There were no significant changes in the requirement of walking aids, orthoses, or external physical assistance. There was no correlation between improvements in walking speed or changes in muscle strength or spastic motor behaviors.

Conclusions: Intensive locomotor training on a treadmill with the assistance of a DGO results in improved overground walking.

Key Words: Locomotion; Paralysis; Physical therapy; Rehabilitation.

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MORE THAN 8000 PEOPLE suffer a traumatic spinal cord injury (SCI) each year in the United States.1-3 Recent statistics indicate that more than 50% of people with SCI have motor incomplete lesions. Approximately half of motor recovery occurs within the first 2 months after initial injury,4-6 with a decreasing rate after 3 to 6 months. At 2 years after injury, neurologic recovery is assumed to be nearly complete.7,9 In patients with an initial motor incomplete SCI, more than 75% regain some form of ambulatory function.10 Although conventional rehabilitation programs enhance performance of functional tasks,11 the loss of strength and coordination substantially limits one’s capacity for overground ambulation training.12,13 In the past 2 decades, body-weight-supported treadmill training (BWSTT) has been proposed as a useful adjunct to enhance locomotor function after motor incomplete SCI.11,13 Such training consists of unloading a portion of a patient’s weight above a motorized treadmill using a counterweight-harness system and providing manual facilitation to help the patient perform stepping movements on the treadmill. Use of BWSTT has been shown to improve coordination of lower-extremity electromyographic activity and postural alignment, and allows13 increased practice of stepping behaviors with diminished or absent supraspinal control.15-17 The benefits of such training in people with incomplete SCI have been reported in several studies in the past decade.18-22 Specifically, in a cohort of subjects with acute and chronic SCI, Wernig et al18 reported substantial improvements in functional walking ability using task-specific treadmill training as compared with conventional rehabilitation. Although the complete results from a randomized controlled trial comparing the effectiveness of BWSTT versus conventional therapy are forthcoming,23 anecdotal reports have confirmed the positive benefits of performing such task-specific training.21,22,25

Despite the potentially positive benefits of BWSTT, its practice in a clinical setting is physically demanding and uncomfortable for personnel providing the assistance. Further, up to 3 people may be needed to facilitate upright posture and normal walking patterns.21 Concerns that traditional rehabilitation approaches are arduous and labor-intensive have caused many researchers and clinicians to search for alternatives. A computer-controlled, driven (ie, motorized) gait orthosis (DGO) has recently been developed to provide assisted loco-
motor training (fig 1). The exoskeletal apparatus helps patients’ lower extremities through symmetric, coordinated trajectories that mimic physiologic walking patterns. In combination with body-weight support, the DGO may provide some of the critical sensory cues necessary to generate the appropriate locomotor pattern, as suggested by work in experimental animal models of SCI.26 Use of such a device in the rehabilitation setting could potentially maximize locomotor function after motor incomplete SCI by increasing the total duration of training and reducing the labor-intensive and costly interventions provided by therapists.

Our primary aim in this multicenter study was to examine whether locomotor training using the DGO would improve overground walking and performance of a multifunctional task by patients with chronic, motor incomplete SCI. In a subpopulation of participants in 1 setting, we further examined whether locomotor training affected lower-extremity motor scores and spastic motor behaviors. Changes in locomotor performance in subjects with SCI after intensive, long-duration gait training using the DGO could establish the therapeutic benefits of automated, task-specific therapy after SCI.

METHODS

The study was carried out in 5 separate SCI rehabilitation units over 2 years. The study protocol was approved by the local ethics committee (ie, institutional review board) of each training facility, and all participants gave written informed consent.

Participants

Twenty patients (18 men, 2 women) with motor incomplete SCI with a neurologic lesion level of greater L1 or higher, with the primary neurologic insult due to trauma or ischemia, participated (table 1). Mean age ± standard deviation (SD) at the time of study enrollment was 40±14 years (range, 16–64y). The average interval between SCI and the onset of DGO training was 5.9±4.9 years (range, 2–17y) (see table 1). Nine subjects were classified by the American Spinal Injury Association (ASIA) as ASIA grade C and 11 as ASIA grade D. Eleven subjects had tetraplegia, and 9 had paraplegia. Sixteen were able to ambulate at least 10m overground with various assistive devices and the assistance of 1 person, although only 4 subjects used overground ambulation as their primary mode of locomotion in the community.

Specific inclusion criteria included more than 2 years since initial SCI, not currently enrolled in physical therapy or other training regimens, and an ability to maintain current antispastic medication dosages throughout training sessions. Under these conditions, the majority of changes in motor behaviors and functional ability were assumed to result from locomotor training provided by the DGO. Additional inclusion criteria were between 16 and 65 years old, lower-extremity weight bearing (standing and/or walking) as part of typical activities of daily living, and medical clearance to participate. Exclusion criteria were presence of concurrent severe medical illness, unhealed decubiti, existing bladder or other infection, thromboembolic disease, significant osteoporosis (as indicated by history of fractures), severe lower-extremity contractures or excessive lower-extremity spasticity that limited range of motion or normal kinematics during locomotor training, history of significant obstructive and/or restrictive pulmonary disease, and inability to tolerate 45 minutes of standing without orthostasis (ie, decrease in systolic blood pressure by 20mmHg or diastolic blood pressure by 10mmHg). Size limitations for the DGO included femur length less than 35cm or greater than 47cm and body weight greater than 150kg.

Training Paradigm

Detailed descriptions of BWSTT have been published.18,27,28 Briefly, training involved unloading a subject over a motorized treadmill using a harness and overhead suspension system, with the amount of unloading adjusted to maximize lower-extremity weight bearing while ensuring correct limb kinematics through stance and swing (minimizing excessive knee flexion during stance phase/weight acceptance).21,29,30

To perform stepping patterns on the treadmill, subjects were assisted by the Lokomat DGO* (fig 1), which is composed of bilateral, exoskeletal leg braces secured to the patient at the pelvis and throughout the lower extremities by adjustable size

![Fig 1. The DGO (Lokomat).](Image)

### Table 1: Description of the 20 Study Subjects

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Sex</th>
<th>Lesion Level/ ASIA Grade</th>
<th>Years Post-SCI</th>
<th>Antispastic Medications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>C6/C</td>
<td>2</td>
<td>60mg baclofen</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>C5/C</td>
<td>4</td>
<td>None</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>C5/C</td>
<td>13</td>
<td>None</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>C6/D</td>
<td>3</td>
<td>None</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>T8/D</td>
<td>4</td>
<td>None</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>T10/C</td>
<td>17</td>
<td>None</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>T9/C</td>
<td>8</td>
<td>None</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>C5/C</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>C7/D</td>
<td>4</td>
<td>30mg baclofen</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>C6/C</td>
<td>3</td>
<td>None</td>
</tr>
<tr>
<td>11</td>
<td>F</td>
<td>C3/D</td>
<td>6</td>
<td>None</td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>L1/D</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>L1/C</td>
<td>6</td>
<td>None</td>
</tr>
<tr>
<td>14</td>
<td>M</td>
<td>C5/D</td>
<td>16</td>
<td>None</td>
</tr>
<tr>
<td>15</td>
<td>M</td>
<td>T10/D</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>16</td>
<td>M</td>
<td>L1/D</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>17</td>
<td>M</td>
<td>C5/C</td>
<td>3</td>
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<tr>
<td>18</td>
<td>M</td>
<td>T7/D</td>
<td>3</td>
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</tr>
<tr>
<td>19</td>
<td>M</td>
<td>T8/D</td>
<td>3</td>
<td>None</td>
</tr>
<tr>
<td>20</td>
<td>M</td>
<td>C7/C</td>
<td>10</td>
<td>None</td>
</tr>
</tbody>
</table>

**NOTE.** Subjects had a mean age of 40.5 years (range, 22–64y). Abbreviations: F, female; M, male.
We used the 6-minute walk test (6MWT) to determine gait endurance. Subjects walked for 6 minutes at their self-chosen pace and could rest when they felt unable to continue. The total walking distance was recorded. Use of any physical assistance, bracing, and/or devices was documented. Each subject used the same assistive device and/or bracing at all sessions.

Subjects performed the Timed Up & Go (TUG) test so that their performance of multiple tasks, including sit-to-stand transfers, gait speed, and postural stability could be assessed. In the TUG test, the time required for a subject to get up from a standard-height arm chair, walk 3 m, return to the chair, and sit down has been used as an indicator of patients who are at risk of falling.

With the exception of the WISCI II, functional ambulation and balance measures are not specific for the population with incomplete SCI. The validity and reliability of these measurements have been assessed in other patient populations and reflect general measures of ambulatory and functional performance.

Secondary. In a subpopulation of the study subjects at 1 center (n=10; subjects 1–9 and 17 in table 1), we also assessed changes in lower-extremity motor scores (LEMS) and the magnitude of spastic motor behaviors. For LEMS, manual muscle testing was performed according to the ASIA guidelines. We assessed 5 key muscle groups of the lower extremities bilaterally; they were the hip flexors, knee extensors, ankle dorsiflexors, great toe extensors, and ankle plantarflexors. Each muscle group was graded between 0 (no muscle contraction) to 5 (able to withstand maximal resistance), with the maximum score being 50.

Two types of spastic motor behaviors are often present after SCI. Spasticity, or velocity-dependent resistance to externally imposed, passive muscle stretch, is common in people with lesions to descending motor pathways. In distal musculature, this behavior may present as clonus, or periodic (6–8 Hz) muscle bursting with lengthening perturbations; although these behaviors can occur in the ankle without substantial changes in the length of the triceps surae. Although these behaviors can occur in the ankle without substantial changes in the length of the triceps surae. In addition, subjects with SCI often experience spasms, which are manifested as hyperactive, multijoint reflexes coexisting with spasticity.

In general, spasms are classified as either extensor spasms, distinguished as knee extension with ankle plantarflexion and hip cocontraction, or flexor spasms, characterized by ankle and great toe dorsiflexion, with knee and hip flexion.

We used the Ashworth Scale to assess spasticity of the knee extensors; involuntary resistance to single-joint passive movement is assigned an ordinal score (range, 0–4), with lower scores representing no spasticity and higher scores indicating increasing resistance to external perturbations. We used the recently validated Spinal Cord Assessment Tools for Spasticity (SCATS) to evaluate spasms and clonus by assigning an ordinal score (range, 0–3) describing either the duration or magnitude of spasm activity after specific manual perturbations (table 2). Flexor spasms were elicited by stroking the sole of the foot with the back of a reflex hammer (ie, Babinski test) with a subject supine and assigning scores according to the

<table>
<thead>
<tr>
<th>Spasm type</th>
<th>0</th>
<th>1 (Mild)</th>
<th>2 (Moderate)</th>
<th>3 (Severe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clonus</td>
<td>NR</td>
<td>1–3s</td>
<td>3–10s</td>
<td>&gt;10s</td>
</tr>
<tr>
<td>Extensor</td>
<td>NR</td>
<td>1–3s</td>
<td>3–10s</td>
<td>&gt;10s</td>
</tr>
<tr>
<td>Flexor</td>
<td>&lt;10° of hip and knee flexion and/or great toe extension</td>
<td>10°–30° of hip and knee flexion</td>
<td>&gt;30° of hip and knee flexion</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviation: NR, no response.
resulting degree of great toe, ankle, knee, and hip movement (see, however, Benz et al52). Extensor spasms and ankle clonus were determined by spasm duration with subjects supine. Extensor spasms were triggered by passively flexing the knee and hip to 90°, then rapidly extending the limb and monitoring the duration of quadriceps contraction. With clonus, the ankle was rapidly dorsiflexed from an initial extended position and held in place while the therapist determined the duration of clonus bursts. The degree and type of spastic motor behaviors varied across the population of SCI subjects tested and did not correlate with level, duration, or completeness of injury.52 Scores were determined on each lower extremity, with the measurements from the more spastic extremity used for statistical analysis.

Statistical Analysis

Measurements of motor performance and functional abilities were assessed before and after 4 and 8 weeks of treadmill training. Inclusion of 3 subjects with neurologic levels of injury below T11 and 4 subjects with prescribed antispastic medications presented 2 potentially confounding factors for enhancing locomotor ability with repeated treadmill training. Statistical analyses were therefore performed using all subjects and after excluding the subpopulation of subjects described above.

The lack of normally distributed measurements (determined by the Shapiro-Wilk test) required nonparametric statistical methods to detect changes in locomotion function and motor impairments throughout training using both ordinal and ratio data. The Friedman analysis of variance by ranks and subsequent pairwise comparisons using the Wilcoxon signed-rank tests were performed to assess differences in pretraining, midtraining, and posttraining measures, with the family-wise error rate noted at P less than .017 to account for multiple comparisons (pretraining to midtraining, midtraining to posttraining, and pretraining to posttraining). We did statistical analyses of the absolute changes in all clinical measurements. For the 10MWT, 6MWT, and TUG test, the relative changes in performance (percentage change from initial evaluation) were also calculated. Specific relationships in changes between the evaluation periods (ie, between the first 4 wk vs second 4 wk of training) were determined with the Wilcoxon signed-rank test, with significance also noted at P less than .05. Spearman correlation coefficients were calculated to assess for correlations between the initial performance on locomotor and functional assessments versus changes in performance of these tasks (absolute and relative) and between changes observed in LEMS, Ashworth Scale, and SCATS measurements with functional improvements.

RESULTS

The mean total number of sessions ± SD for all subjects was 26±4.3 during the 8 weeks (range, 24–37 sessions). The average distance ambulated during single training sessions was 1279±782m (range, 200–1893m) at a walking speed of .65±.03m/s (range, 42–67m/s). Mean unloading during treadmill training was 37%±17% (range, 0–5%) of body weight (fig 2).

Primary Outcome Measures

Only 2 subjects showed improvements in walking ability, as determined by WISCI II scores. One subject who used 2 crutches before the training series could walk with only 1 cane after training but still required a leg brace (WISCI II score increased from 12 to 15). Another subject used a single straight cane before training and did not need assistive devices after 8 weeks of locomotor therapy (WISCI II score change from 19 to 20). All subjects who were nonambulatory before training did not regain locomotor function. We found no significant difference for the WISCI II (χ² test=3.0, P=.22) across all ambulatory subjects or after excluding subjects taking prescribed antispastic medications or subjects with lesion levels below T11 (all subjects in these 2 groups had no change in their WISCI II scores).

We found improvements in speed and endurance in overground gait assessments in nearly all subjects after training with the DGO (fig 3). The 10MWT showed a significant increase in mean gait speed (.11±.01m/s) after locomotor training (χ² test=20.1, P<.001). This change corresponded to a 56%±60% improvement over initial control (pretraining) values. Three of the 5 subjects who could walk faster overground than the maximal speed of the Lokomat (.66m/s) before training improved their gait speed after training. Significant changes for all subjects were found from pretraining to midtraining evaluations (ie, 0 to 4 wk; P<.01) and from midtraining to posttraining assessments (ie, 4 to 8 wk; P<.01), with no difference observed in the rate of improvement when we compared the initial versus final 4 weeks of training (P=.69).

Gait speed increased significantly after subjects with injury levels below T11 or those prescribed antispastic medications were excluded. Specifically, the mean increase in gait speed in subjects with lesion levels at or above T11 was .09±.09m/s (P=.001) versus .16±.12m/s in subjects with lesions below T11. Despite this large relative difference between groups, statistical differences were not calculated because of the small sample size. The average increase in gait speed in subjects not taking antispastic agents was .09±.09m/s (P<.001), which was also less than that in the group of ambulatory subjects who were prescribed these agents (.13±.10m/s).

Similar results were observed for the 6MWT, with 15 of 16 subjects improving their walking distance. The mean increase in distance ambulated for all subjects was 32.3±37.5m (relative increase of 53%±50%; χ² test=26.4, P<.001). Similar to the 10MWT, significant differences were found during the initial (P=.01) and final 4 weeks of training (P<.01), with no difference in the rate of improvements during these periods (P=.46). Significant differences were also noted after we excluded subjects with lesion levels below T11 (46±39m, P<.001 vs 37±24m in subjects with <T11 lesions) and subjects taking antispastic medications (47±38m, P<.001 vs 30±22m in subjects prescribed agents).
For the TUG test, there were improvements in all but 2 of the ambulatory subjects. The mean decrease in time to perform the TUG test was 25 ± 10 seconds (32% ± 19%, χ² test=22.1, P<.001), with the largest changes after the first versus second 4 weeks of training (mean decrease, 20 ± 26s, P<.01 vs 5 ± 6s, P<.01, respectively). The difference in the rate of improvements in the performance of the TUG differed significantly (P<.001), however, with slightly less improvement in subjects with lesion levels greater than T11 (21 ± 18s) and in those not taking antispastic medications (24 ± 32s). The differences, however, were both statistically significant (P<.001).

For the changes in locomotor ability during the 10MWT, 6MWT, and TUG test, there were significant correlations between the initial pretraining performance and the magnitude of the improvements (fig 4). Compared with the relative (ie, percentage) change from the initial value before locomotor training, correlation coefficients showed significant negative relationships for the 10MWT (ρ=-.67, P<.01) and the 6MWT (ρ=-.51, P<.05), indicating that the slower ambulators had the greatest relative improvement. This was not true for the TUG test, because the correlation was not significant (ρ=.44, P=.08).

Secondary Outcome Measures

In addition to gait and functional assessments, LEMS and spastic motor behavior tests were performed at only 1 of the 4 test centers. The mean improvement in LEMS total scores for 10 subjects tested before, at the midpoint, and after locomotor training was 2.5 (LEMS initial score, 32 vs final score, 35; n=10; χ² test=13.4, P=.016), with significant differences only between the 4- and 8-week assessments. Changes were not specific to any individual muscle groups. For 9 ambulatory subjects, changes in LEMS did not correlate with the absolute or relative changes in performance on the 10MWT, 6MWT, or TUG test, with the lowest coefficient being the changes in LEMS versus relative changes in the 10MWT (ρ=.44, P=.20). Notably, the correlation was negative, whereas a positive correlation between LEMS and gait speed changes was expected. An example of this relation is shown in figure 5 for LEMS scores versus the relative (ie, percentage) increase in gait speed for the 10MWT.
For spastic motor behaviors, we used the Ashworth Scale to evaluate the involuntary resistance to passive stretch of the quadriceps muscle groups and assessed clonus and multit Joint extensor and flexor spasm activity with the SCATS. Averaged scores for each assessment before and after 4 and 8 weeks of locomotor training are shown in Figure 6. Of these measures, only extensor spasm scores using the SCATS decreased substantially after 8 weeks of training (P < 0.01). Changes in all spastic motor assessments did not correlate with changes in relative or absolute measures of the 10MWT, 6MWT, or TUG test (smallest ρ = 0.41, P = 0.27).

**DISCUSSION**

Our primary purpose in this study was to determine whether intensive locomotor training using a robotic device (DGO) would improve ambulatory and functional capabilities of people with chronic motor incomplete SCI. Our main findings were 3-fold. First, there were no significant changes in WISCI II scores, which indicate the degree of physical assistance, use of assistive devices, and lower-extremity bracing. Significant changes however, were observed in functional limitations, including increased overground gait speed (10MWT), improved gait endurance (6MWT), and decreased time necessary to perform the TUG test. Ambulatory subjects whose locomotor and functional abilities were most impaired experienced the greatest benefit from the training, as shown by higher relative and absolute gains in performance on the standardized assessments. Finally, there were improvements in LEMS and decreases in specific spastic motor behaviors (ie, extensor spasms), but they did not correlate with changes in walking function. The results of this preliminary assessment of the effects of long-duration, locomotor training using the DGO in combination with BWSTT indicate that robotic treadmill training can elicit substantial improvements in overground functional ability.

The role of manual-assisted BWSTT in enhancing motor recovery and improving ambulation after neurologic injury has been studied intensively for the past 15 years (see a review by Barbeau et al). Increases in lower-extremity motor strength, walking ability, and postural stability have been observed in people with motor incomplete SCI and stroke in the acute through chronic stages of recovery. Such changes have been compared favorably with conventional rehabilitation, indicating that task-specific, manual-assisted BWSTT may maximize neurologic recovery and gait restoration. A primary limitation of such therapy however, is the labor-intensive efforts required of the therapists. Manual facilitation of the lower extremities and trunk to generate appropriate kinematics associated with stepping behaviors can require substantial effort, especially during training of patients with significant weakness or spastic motor behaviors. As many as 3 people are often needed to help patients with their stepping behaviors, and this can limit the extent to which such therapy can be given in the clinical setting.

Robotic- and manual-assisted BWSTT are similar in their attempt to help patients practice walking by facilitating kinematically correct stepping patterns. The advantage of delivering robotic-assisted training is that specific locomotor interventions can be done with the help of only 1 therapist and can be performed for a longer duration, thereby increasing the amount of practice of stepping behaviors. Our results suggest that the improvements in locomotor function in our ambulatory subject population were statistically and functionally significant, with the mean increase in gait speed and endurance greater than 50% of pretraining values. These improvements were qualitatively similar to those achieved by people with a similar diagnosis and chronicity of injury who performed therapist-assisted BWSTT. Furthermore, similar to studies that investigated the effects of manual-assisted BWSTT, people in the chronic stages of injury who were not ambulatory before training did not regain functional, overground ambulation capability after training on the Lokomat. It remains to be determined whether robotic-assisted BWSTT can produce functional improvements similar or greater than those achieved through manual-assisted locomotor training or conventional therapy.

Five caveats about the improvements in locomotor ability after robotic-assisted treadmill training in people with chronic SCI should be addressed. First, despite improvements in at least 1 of the functional gait assessments in all subjects, the extent of recovery was dependent on their initial ambulatory capacity. Specifically, subjects who had the greatest improvements in gait speed, endurance, and the TUG test times were generally the most impaired, as determined by the correlation coefficients between initial and relative improvements in functional performance. These results indicate that the locomotor training with the DGO may have been insufficient to produce greater improvements in the motor recovery of higher-functioning patients or that their recovery had maximized their neurologic recovery. Indeed, 4 subjects ambulated at higher overground gait speeds than the DGO could accommodate and thus showed smaller relative improvements. Future studies should address the most appropriate criteria for selecting subjects for locomotor training using the DGO.
Second, enrollment of subjects with neurologic injury levels below T11 or of subjects taking antispastic medications presented 2 confounding factors that may have influenced the results of robotic-assisted training. Damage to lower-extremity peripheral nerves (as may occur with lower-level injuries) may reduce the conduction of afferent signals to the spinal cord that are thought to be essential in enhancing spinal plasticity associated with locomotor improvements. Further, various antispastic medications affect locomotor activity in people with SCI and may alter the rate of locomotor recovery with training. Our study results indicate that the mean improvements in gait speed and endurance or the TUG test were not altered considerably after subjects with these potentially confounding variables were excluded. Indeed, there were substantial locomotor improvements in all ambulatory subjects with lower-level injuries or who were prescribed antispastic agents, although the small sample size prevents extrapolation to a larger population. The rate and extent of improvements in locomotor function in people with lower neurologic level injuries or who took various prescribed pharmacologic agents that alter motor behaviors requires future investigation.

Third, our assessment of walking ability shows that the prediction of improvement in walking capacity of people with SCI is limited if it is based only on the assessment of static motor behaviors, such as voluntary muscle force or spastic motor behaviors, which represent standardized measurement procedures in patients with an SCI. For example, despite previous studies that have suggested a relation between LEMS and overground walking ability, there is evidence that suggests that, after a specific treadmill training intervention, changes in LEMS do not correlate with changes in overground walking speed, as shown in this study. Although the motor score is likely to reflect the spontaneous recovery of corticospinal function, the improvement in walking ability also reflects the plasticity of spinal neuronal centers below the level of lesion. There is evidence that suggests there is greater recruitment of lower-extremity motor pools during treadmill stepping or voluntary multijoint movements than there is with voluntary activity generated during single joint movements, as evaluated during LEMS assessments. A comprehensive assessment of patients with SCI should include tests that address the functional performance (ie, walking tests), as used in this study.

In addition, spastic motor activity was not significantly altered except for the reduction in multijoint extensor spasms, characterized by hip cocontraction, knee extension, and ankle plantarflexion to imposed hip and knee extension in the supine position. The changes in functional performance reflect a substantial alteration in voluntary motor activity in the absence of changes in most clinical spasticity measurements. This observation in 10 chronic SCI subjects is inconsistent with data presented in a case report that illustrated reduction in spastic motor behaviors in a person 5 years after injury after patterned neural stimulation, including BWSTT.

Further, in our study, the WISCI II test did not detect changes in ambulatory function, whereas improvements in other standardized gait or functional assessments showed substantial improvements. The WISCI II test may be less sensitive to changes in specific interventions, or the extent of locomotor training may have been insufficient to produce substantial improvements in subjects’ use of bracing and assistance. The 10MWT, the 6MWT, and the TUG test were more sensitive, however, reflecting improvements in nearly all subjects. Although these later tests were developed primarily to assess the mobility of geriatric patients, they nevertheless can reflect the walking and functional ability of ambulatory people with SCI. A further study is required to evaluate the validity and reliability of these clinical assessments in patients with incomplete SCI.

Finally, our study results indicated improvements in locomotor ability for a particular subpopulation of subjects tested. Although many subjects show considerable improvements in overground walking speed and endurance, the significant correlation between relative changes in ambulation and initial overground walking speed and endurance indicate that the largest gains were in the most impaired subjects. Considering the limits of the DGO we used, it is likely that BWSTT without robotic assistance for people walking at higher initial overground speeds, particularly those who walked at speeds faster than the maximal velocity of the DGO, could result in greater improvements in speed and endurance. With continued progress in the field of rehabilitation robotics, it will be necessary to develop specific treatment algorithms to help clinicians decide which specific physical interventions are most appropriate for maximizing recovery and function in patients with neurologic injury.

CONCLUSIONS

The use of task-specific treadmill training with the DGO to improve functional overground mobility is promising. Robotic devices that allow practice of BWSTT in the rehabilitation setting may reduce the number of personnel needed to provide such therapy and relieve therapists from the physical demands of the task. Robotic-assisted BWSTT can be further enhanced by increasing the frequency and duration of training. Continued research however, is necessary to advance the development of both specific physical interventions and treatment algorithms to help clinicians decide which physical interventions are most appropriate for patients with specific functional limitations.

References


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Supplier
a. Hocoma AG, Industriestr 4b, CH-8604 Volketswil, Switzerland.