Prospective, Blinded, Randomized Crossover Study of Gait Rehabilitation in Stroke Patients Using the Lokomat Gait Orthosis

Andreas Mayr, MS, Markus Kofler, MD, Ellen Quirbach, PT, Heinz Matzak, MD, Katrin Fröhlich, MD, and Leopold Saltuari, MD

Objective. Treadmill training with partial body weight support has been suggested as a useful strategy for gait rehabilitation after stroke. This prospective, blinded, randomized controlled study of gait retraining tested the feasibility and potential efficacy of using an electromechanical-driven gait orthosis (Lokomat) for treadmill training. *Methods*. Sixteen stroke patients, mostly within 3 months after onset, were randomized into 2 treatment groups, ABA or BAB (A = 3 weeks of Lokomat training, B = 3 weeks of conventional physical therapy) for 9 weeks of treatment. The outcome measures were the EU-Walking Scale, Rivermead Motor Assessment Scale, 10-m timed walking speed, 6-minute timed walking distance, Motricity Index, Medical Research Council Scale of strength, and Ashworth Scale of tone. *Results*. The EU-Walking Scale, Rivermead Motor Assessment Scale, 6-minute timed walking distance, Medical Research Council Scale, and Ashworth Scale demonstrated significantly more improvement during the Lokomat training phase than during the conventional physical therapy phase within each 3-week interval. *Conclusions*. Despite the small number of patients, the present data suggest that the Lokomat robotic assistive device provides innovative possibilities for gait training in stroke rehabilitation while eliminating prolonged repetitive movements in a nonergonomic position on the part of the physical therapist.

Key Words: *Locomotion—Stroke—Assessment scores—Automated gait orthosis—Lokomat.*

After hemiplegic stroke, treadmill training with partial body weight support and manual assistance to control the trunk and legs has been suggested as a technique to facilitate functional walking. Although the results of randomized clinical trials during initial rehabilitation have not yet shown a consistent benefit of the various applications of the technique,[1] experimental studies of cortical and spinal control of motor learning and task-oriented training suggest that this approach may improve walking outcomes compared to more conventional physical therapies,[2,3] in part by allowing patients to relearn motor patterns through progressive repetitive practice of spatiotemporal and kinetic parameters of walking, including limb loading, velocity, cadence, and stride length.[4] However, certain disadvantages of treadmill training render the execution of physiological locomotor patterns difficult. Control of the joints of the lower limbs during the training session, attempts at repeated execution of kinematically normal steps throughout the entire training session, and the exhausting and nonergonomic working position of the physical therapist limit a potentially useful rehabilitation strategy.

New automated locomotion systems have been developed for facilitation of step training and to eliminate manual assistance by the physical therapist. One robotic assistive treadmill device, the Lokomat, has been commercially available for several years. No reports of efficacy for walking outcomes have been reported, although several trials are in progress. We report a crossover comparison trial that alternated 3 weeks of 20-minute add-on training daily with the Lokomat compared to the conventional training at our institution.

From the Department of Neurology, Hospital Hochzirl, Zirl, Austria. Andreas Mayr and Markus Kofler contributed equally to this paper.

Address correspondence to Markus Kofler, MD, Department of Neurology, Hospital Hochzirl, A-6170 Zirl, Austria. E-mail: markus.kofler@i-med.ac.at.

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;21:307-314.

DOI: 10.1177/1545968307300697

METHODS

Patients

Sixteen consecutive patients with a history of cerebral ischemic or hemorrhagic stroke (Table 1) and inability to walk unaided granted informed consent to

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Table 1. Demographic Patient Data

Patients	Sex, Male/Female	Age, Years	Onset, Months	Additional Symptoms	Group Allocation	Lesion on CCT	Etiology
1	F	66	1	Aphasia	1	L MCA	Ischemia
2	F	63	2.5	R Hemianopia R Hemineglect	1	L BASAL	Hemorrhage
3	F	65	2		1	L MCA	Ischemia
4	F	42	3		2	R MCA	Ischemia
5	F	26	3	Aphasia	2	L MCA	Ischemia
6	F	75	0.5		2	R MCA	Ischemia
7	F	57	1		2	R MCA	Ischemia
8	F	78	1		2	R MCA	Ischemia
9	M	44	10		1	L MCA	Hemorrhage
10	F	78	5		2	L MCA	Ischemia
11	M	64	8	L Hemianopia Aphasia	1	L MCA	Ischemia
12	M	71	1.5		1	L BASAL	Hemorrhage
13	M	67	1.5		2	R BASAL	Ischemia
14	M	65	2		1	R BASAL	Ischemia
15	M	67	1.5	L Hemianopia L Hemineglect	2	R MCA	Ischemia
16	F	87	1		1	R MCA	Ischemia
N = 16	Male = 6 Female = 10	63.4	2.8			R = 8 L = 8	Ischemia = 13 Hemorrhage = 3

R, right; L, left; MCA, territory of the middle cerebral artery; BASAL, basal ganglia; CCT, cerebral computerized tomography.

the study. The patients were assigned to 1 of 2 groups based on a random number list. Initially, 12 patients required full support by a physical therapist during overground walking, 3 patients used a cane with tactile or verbal assistance, and 1 patient was able to walk unaided with a cane with stand-by supervision. Three patients had hemianopia and hemineglect, and 3 patients had aphasia. Nevertheless, all patients were able to understand and follow verbal instructions. All 16 patients in this study presented with typical signs and symptoms of the upper motor neuron syndrome: abnormal postures, hyperreflexia and hypertonus, impairment of selective motor control and proprioception, weakness, and primitive motor patterns. No patient suffered from severe orthopedic problems or neuropsychological deficits that would preclude participation. All subjects were inpatients and received occupational and speech therapy if necessary. Patients wore comfortable clothing and shoes during therapy, and ankle foot orthoses were allowed if deemed necessary.

Study Design

The study was designed as a prospective, randomized, blinded, parallel-group (ABA-BAB), 9-week trial to compare the efficacy of Lokomat treatment (A) with conventional physical therapy (B), as well as to determine the most efficient sequence of training phases. Group 1 (n = 8) received 3 weeks of Lokomat training (phase I), followed by 3 weeks of conventional physical therapy (phase II), followed by 3 weeks of Lokomat training (phase III) (ABA). Group 2 (n = 8) received 3 weeks of conventional physical therapy (phase I), followed by 3 weeks of Lokomat training (phase II), followed by 3 weeks of conventional physical therapy (phase III) (BAB). Two senior therapists (AM, EQ) applied the respective treatment 5 days per week. Each patient was evaluated using 7 scales assessing gait and motor function at baseline and after 3, 6, and 9 weeks.

The Lokomat

The Lokomat consists of a treadmill, a driven gait orthosis, a suspension system to provide body weight support, and a computer for individual adaptation of gait within preset safety limits. A second computer screen provides the patient with online information about speed, time, and distance.[5] A Lokomat treatment session of 45 minutes comprised putting on the harness, attaching and adjusting the Lokomat, and the actual training of up to 30 minutes. The patient practiced a physiological gait pattern in a task-specific manner over the defined time. Four parameters were adapted to ability, strength, and endurance of the patient: (1) body weight support,

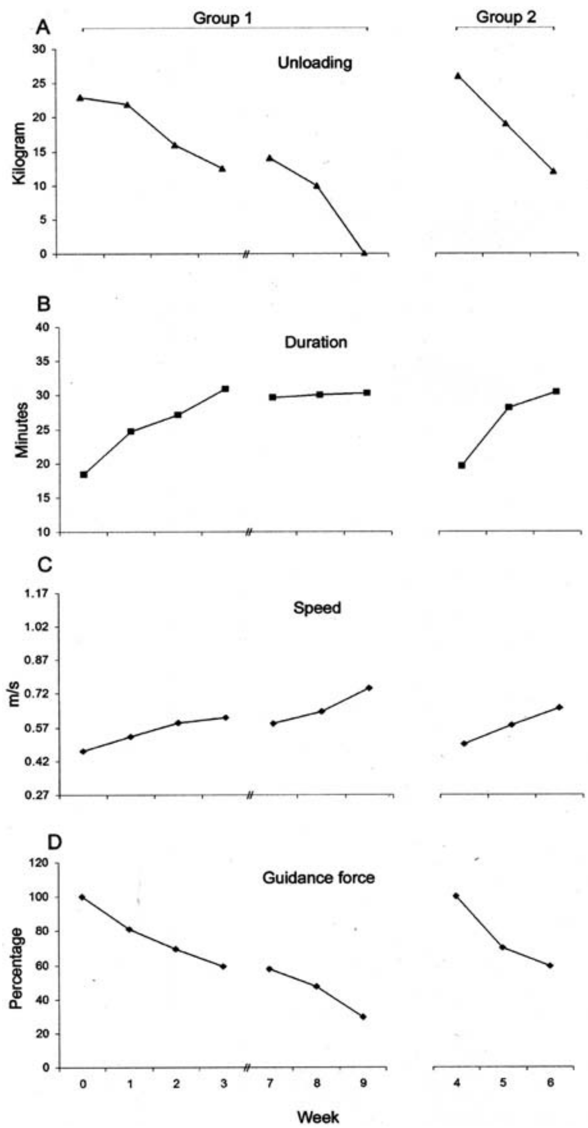

Figure 1. Weekly changes in mean walking speed (m/s), duration (minutes), unloading (kilograms), and guidance force (percentage) during Lokomat training phases (group 1, phases I and II; group 2, phase II) in both groups.

set initially at 40% on a spring scale, was gradually reduced to 0%[6]; (2) walking duration was increased to a maximum of 30 minutes; (3) ambulation velocity was initially set at 0.28 m/s, then gradually increased to a maximum of 0.83 m/s; and (4) guidance force provided by the Lokomat on the hemiparetic leg was gradually reduced from 100% to 15% (Figure 1A-D). Percent reduction of the guidance force of the Lokomat allows for progressively active participation by the patient. Thus, at 75%, the patient executes one fourth of the workload, at 30% executes 70% of the work, and so on. Adjustments of all training parameters were undertaken according to the patient's muscle tone, gait control, and gait quality (ie, adequate knee control during stance, free swing phase, first heel contact, and satisfaction of the patient). If a patient was unable to keep up with any of the adjustments with resultant deterioration in gait quality, changes were reversed or carried out to a lesser extent. During the Lokomat training phases, patients received no additional overground training.

Conventional Physical Therapy

Conventional physical therapy consisted of neurophysiological concepts such as Bobath[7] and cortical facilitation techniques according to Perfetti.[8] Strategies followed in these sessions emphasized general bilateral and 3-dimensional movements required for turning, rolling, kneeling, sitting, standing, and so on; facilitation of selective movement on the paretic side of the body; integration of the selective movement in functional activity; exercise for improving balance; and so forth. Overground walking was an integral part of conventional therapy but with less emphasis on distance walked than on gait quality (eg, equilibrium, stability during stance phase, foot clearance during swing phase, prepositioning of the foot, heel contact, body weight transfer). A session lasted 45 minutes, but due to different reasons (eg, readjustment of body position, transfers, intermittent necessity to void, changing from one therapeutic strategy to another, verbal interaction with the therapist, limited endurance, patient's inability to focus his or her attention on one special aspect over a long period of time, etc), the actual effective treatment time was less and approximated, on average, 30 minutes, thus being comparable to the effective Lokomat training time. To achieve clear differentiation between the individualized hands-on training strategies in conventional physical therapy and automatized repetitive Lokomat training, use of additional automated training equipment such as a treadmill, ergometer, or stepper was not permitted.

Outcome Measures

Each patient was evaluated by 1 of 2 neurorehabilitation specialists (HM, KF), who were blinded as to the patients' group assignment. Changes in motor function were assessed using 7 scales. All values were recorded on a standard form.

Changes in function were assessed with a modified EU-Walking Scale[9] and the Rivermead Motor Assessment Scale (RMA), part 3, "gross function."[10] The RMA was assessed immediately after the training session.

Changes in walking speed and duration were measured with the 10-m timed walking speed (10-m TWS) and the 6-minute timed walking distance (6-minute TWD).[11] All participants were asked to walk on a 10-m grid on a flat surface. They began each walk before the starting line so that they could accelerate and attain a stable speed before the actual test distance began. Patients who required therapeutic support were asked to walk as well as possible without pausing, as rapidly as possible, and with no verbal instructions from the investigator during ambulation. Manual support was given if necessary to provide safety, acknowledging that any assistance could affect the patient's performance. Walking time in the 10-m TWS was measured with a handheld stopwatch, and the distance covered in the 6-minute TWD was assessed with a tape measure. One patient, who was unable to walk initially, was assigned a value of 200 seconds in the 10-m TWS (5% longer than the slowest patient) and a value of 16 meters in the 6-minute TWD (11% shorter than the slowest patient) in order not to lose his data as he, too, improved throughout the study.

Changes in muscle strength were assessed with the Medical Research Council (MRC) Scale[12] and the Motricity Index (MI).[13] The MRC Scale was obtained separately for 5 muscles (triceps surae, quadriceps, hamstrings, iliopsoas, and gluteus maximus muscles) and then added to a maximum sum score of 25 for the affected lower extremity. The MI contains the assessment of hip flexion, knee extension, and ankle dorsiflexion with 6 grades. A total score for the limb was obtained by adding 1 point to the sum of the scores of all 3 individual movements (maximum score of 100).

The Ashworth Scale[14] was used to assess changes in muscle tone. It was applied to the same 5 muscles as the MRC Scale. A maximum score of 20 was calculated by adding the individual scores for each muscle in the affected lower limb. The scores were obtained for each patient in both groups at baseline and after 3, 6, and 9 weeks.

Statistical Analysis

Statistical comparisons were performed with SPSS 11.0 for Windows. The Kolmogorov-Smirnov test served to assess the distribution of continuous variables (10-m TWS and 6-minute TWD). As the 10-m TWS did not meet the assumptions of normality, nonparametric tests were used to compare both metric and ordinal categorical data. Differences were calculated between measurements made at baseline and at the end of phases I, II, and III, respectively. Within-group comparisons of treatment effects relative to baseline were carried out with the Wilcoxon test, and between-group comparisons were performed with the Mann-Whitney *U* test.

RESULTS

All patients completed the study without difficulty, and no adverse events were encountered. Patients improved in gait performance and motor function as reflected by various scales. Initially, 5 patients were unable to walk in the Lokomat for 30 minutes but succeeded in doing so within 1 to 3 days. Body weight support could be reduced from 40% to 0% within 21 days. Patients began with a mean training speed of 0.47 m/s (range, 0.28-0.56 m/s) and increased to 0.75 m/s (range, 0.56-0.83 m/s) after 9 weeks, whereas guidance force provided by the Lokomat on the hemiparetic leg was reduced, on average, to 30% (range, 100%-15%) (Figure 1A-D).

In group 1, statistical comparisons revealed significant improvement during phase I (Lokomat) and phase III (Lokomat), respectively, in EU-Walking Scale (P = .016; P = .046), RMA (P = .017; P = .010), MRC Scale (P = .011; P = .011), and 6-minute TWD (P = .018; P = .012). The Motricity Index showed significant improvement in phase I (P = .012), and the Ashworth Scale showed significant improvment in phase III (P = .024).

Median walking speed, as assessed by the 10-m TWS, tended to improve during all phases but improved significantly from 0.13 m/s at baseline to 0.30 m/s at end of treatment (P = .036). No significant improvement was noted in phase II (conventional physical therapy) for any scale (Figure 2A-G).

In group 2, significant improvement occurred during phase I (conventional physical therapy) in RMA (P = .041), 6-minute TWD (P = .018), and MI (P = .017); in phase II (Lokomat) in the EU-Walking Scale (P = .010), MRC Scale (P = .012), 6-minute TWD (P = .012), and Ashworth Scale (P = .017); and in phase III (conventional physical therapy) in the 10-m TWS (P = .035). Walking speed did not significantly improve (0.14 m/s at baseline and 0.27 m/s at end of treatment; P = .327) (Figure 2A-G).

Between-group comparison showed no significant differences at baseline (EU-Walking Scale: P = .574; RMA: P = .878; 10-m TWS: P = .878; 6-minute TWD: P = .959; MI: P = .279; Ashworth Scale: P = .959; MRC: P = .328), thus indicating that the differences in outcomes resulted from the different training strategies.

DISCUSSION

This comparison of the effects of Lokomat training with those of conventional physical therapy in 16 hemiparetic patients demonstrated the efficacy of automated gait training to improve walking on 7 scales of function, including speed, endurance, muscle strength, and muscle tone. The design and small sample size, as well as the use of multiple outcome measures without defining and

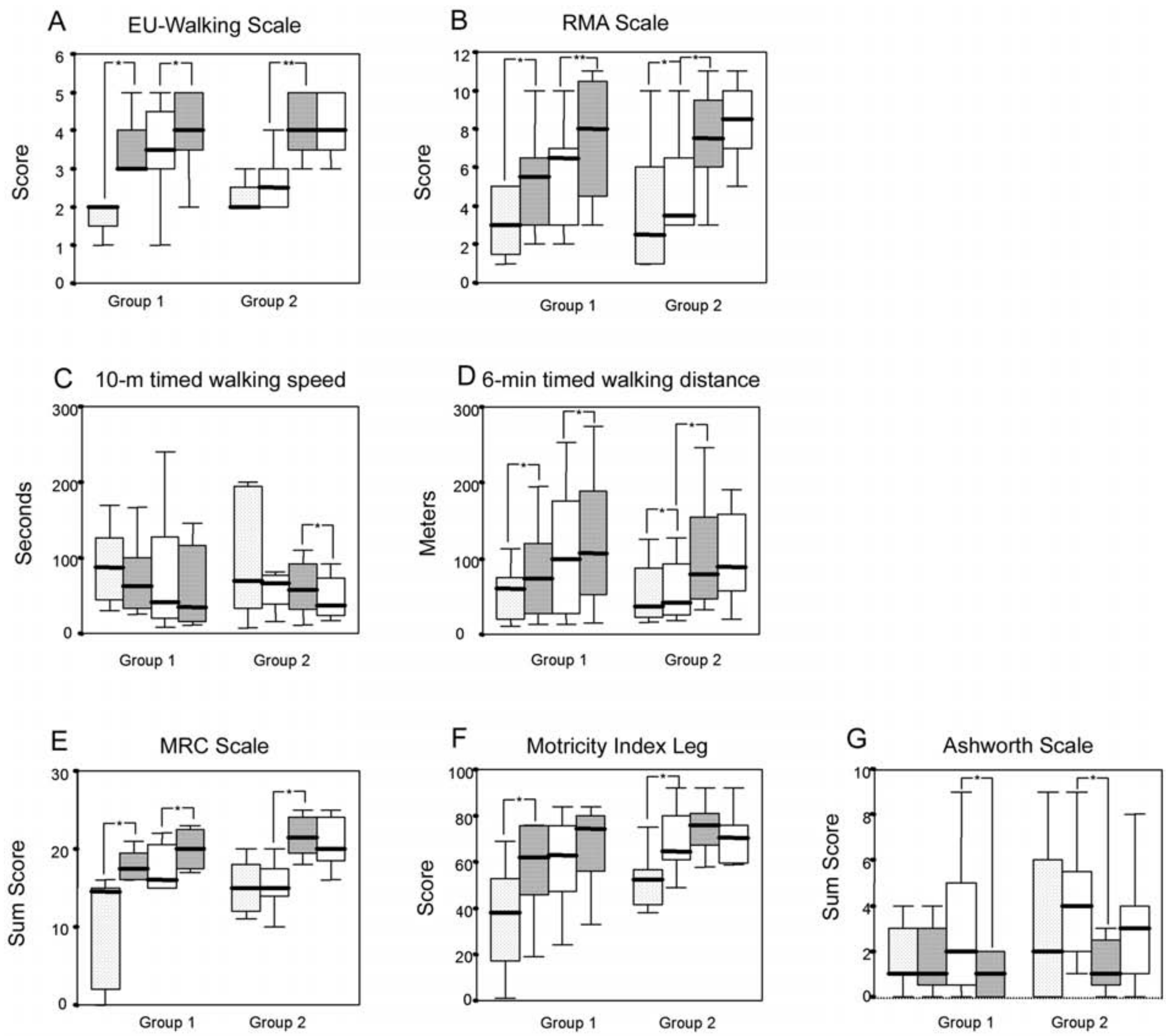

Figure 2. Assessment of *function* with modified (A) EU-Walking Scale and (B) Rivermead Motor Assessment (RMA) Scale, *walking speed and duration* with the (C) 10-m timed walking speed and (D) 6-minute timed walking distance, *muscle strength* with the (E) Medical Research Council (MRC) Scale and (F) Motricity Index, and *muscle tone* with the (G) Ashworth Scale. Each box of the box plots represents 50% of all values, intersected by the median. The whiskers indicate the smallest and largest values. Punctuated boxes depict measurements at baseline, gray boxes following Lokomat therapy, and white boxes following conventional physical therapy. Asterisks above the columns define the level of significance of within-group comparisons (*$P < .05$; **$P < .01$).

powering for a primary outcome, pose potential limitations for the interpretation and generalization of the results.

Study Design and Statistics

The ABA single case study design was chosen to limit both study duration and the number of subjects in this pilot trial. Although this is an acceptable experimental design, it fails to take into account carryover effects between phases.[15] Studying 2 groups of patients (ABA and BAB), however, may help to minimize these carryover effects: ultimately, when comparing 3 phases A with 3 phases B, time is a less critical factor as the data derive from different training phases throughout the study in both groups. Further detailed analysis of the data demonstrated a greater benefit in patients who began with Lokomat training rather than with conventional therapy, and the former was also more effective in phase I as compared to phases II and III. This indicates that Lokomat training applied at the beginning of the motor learning process may more effectively assist the patient in attaining gross coordination of walking and thus may create an important basis for more individualized and varied training with the physical therapist later.[16]

Particularly in early stages of stroke recovery, conventional physical therapy is made difficult by factors such as poor balance, weakness, malalignment and joint instability, hypertonus, changes in body perception, and so on. Training with the Lokomat can aid in overcoming some of these problems by stabilizing the pelvis and trunk, by supporting the patient's body weight to prevent knee buckling and aid foot clearance, and by executing an automated, perhaps more physiological gait pattern under spatiotemporal control.

Two experienced therapists performed the training with the Lokomat and the conventional physical therapy. Advantages of conventional therapy (eg, personal contact to the patient, enabling individualized adaptation of therapy) may be weighed against certain high expectations of success using a new technical development.

Nonparametric tests (Wilcoxon and Mann-Whitney *U*) were chosen because of the nonnormal distribution of some of the data and were applied for comparison of both metric and ordinal categorical data. Despite inhomogeneous data and a small sample size, nonparametric testing still revealed statistically significant differences.

The Lokomat

New equipment has been developed to automate training and thus to ameliorate the efforts of the physical therapist.[5,17-19] The Lokomat combines new technology with the recognized advantages of manual treadmill training eg, optimal loading,[20] adequate sensory input,[21,22] optimal hip extension,[23] interlimb coordination,[24-26] task-specific locomotion movements,[27] and early initiation and prolonged training sessions.[28] The mechanical aid fulfills many of the criteria of a physiologically sound gait pattern, as described in gait analysis (ie, executing separate stance and swing phases, providing sufficient foot clearance during swing, prepositioning of the foot prior to stance phase, stabilization during stance, and adequate step length).[29] It allows for optimal individual adaptation to gait in a stable upright position, the possibility of cyclic reproduction of normal gait patterns,[30] high frequency of repetition, correct sensory feedback to higher centers, high patient motivation, and alleviation of the physical therapist's workload.

Recent publications[31-33] emphasize that automatized gait training may be at least as effective as manually assisted treadmill training and that patients may walk more symmetrically, with less spasticity and better joint angle displacements and electromyographic patterns. Patients reported the automated training to be more comfortable than manually assisted training.

Hesse et al compared body weight–supported treadmill training with Bobath-based, conventional physical therapy in 9[4] and 7[34] nonambulatory stroke patients, respectively. Their conclusion was that additionally applied treadmill training augmented gait ability and other motor functions in severely affected nonambulatory hemiparetic patients and that body weight–supported treadmill training was superior to physical therapy with regard to restoration of gait function. Whether or not patients were randomized or the examiners were blinded was not made clear in their methods. Visintin and Barbeau[6] and Visintin et al[35] concluded that in stroke patients who entered a randomized trial at about the same time as our subjects, treadmill training with adequate body weight support resulted in better walking ability than treadmill training with full weight bearing. The differences in attained walking speed and other outcomes may have been of statistical but not clinical significance. Other early rehabilitation trials of treadmill training with weight support compared to conventional training have revealed equivalence for walking outcomes.[1]

Lokomat training improves gait in stroke patients. Husemann et al[36] reported improvement in single stance phase on the paretic leg during overground walking, increased muscle mass, and reduced fat mass with a 30-minute regime over 4 weeks. Notably, our study revealed significant improvement in function during a 6-week period of Lokomat training, indicating the dependency of functional recovery on intensive and longer training periods.

Krewer et al[37] found a significant increase of oxygen uptake during loading of the weight-accepting limb in healthy subjects and stroke patients. Thus, Lokomat training may also improve cardiovascular fitness,[38] which is a prerequisite for increasing distance in daily walking. When patients are able to execute a well-coordinated skill at lower speeds, velocity should then be increased so as to automatize the functional ability.[39,40] Reduction of the guidance force may lead to an increase in muscle contraction and strength in the hemiparetic leg; it should be reduced when the patient is able to walk without body weight support at a moderate velocity. Optimal training can be achieved only by performance at or near the limit of individual capability. In using the Lokomat, adaptation of treatment should continually challenge the patient. In our experience, patients benefit the most from adapting training parameters in the following order: (1) reduction of body weight support, (2) increase in walking duration, (3) increase in velocity of walking, and (4) reduction of guidance force on the hemiparetic leg. Applying these strategies, patients in the present study were able to achieve gait even after a long period of time without walking, in contrast to the findings of Jorgensen et al,[41] who stated that improvement in walking function is possible only within the first 11 weeks following stroke.

Limitations of the Lokomat become evident in later stages of rehabilitation. Movements required for functional walking depend on interactions between perception and motor ability, as well as between the individual, task, and environment.[42] The Lokomat cannot provide the variable environments and movement patterns necessary for adaptation to daily living. Early application of Lokomat training can only rehearse a mechanical pattern, as a prerequisite for independent walking.

Evaluation of Scales and Scores

Because walking ability encompasses more than a mere repetition of steps, the most appropriate tests proved to be those assessing function (RMA, EU-Walking Scale), endurance (6-minute TWD), and strength (MRC Scale). The gross function section of the RMA proved to be the most appropriate scale; its 13 items could easily be carried out in a short time. Others, however,[34] found that the RMA was not sensitive enough to reflect functional improvement in their investigation of treadmill training. However, the movements tested in RMA are vital as prerequisites for gait. A modified version of the EU-Walking Scale was chosen for its definition of walking aids, as a simple alternative to the widely used Functional Ambulatory Categories.[43,44] Unfortunately, to our knowledge, no validation of the EU-Walking Scale is available.

As a measure of function, the 6-minute TWD was advantageous because of its duration, which minimizes relative measurement errors.[45] Although most patients tired quickly in the early stages of the rehabilitation process, their stamina increased with time. Due to its short execution time and therefore higher susceptibility to measurement errors, the 10-m TWS proved to be less useful. The MI, which measures muscle strength during defined selective movements, revealed no significant difference between Lokomat training and conventional physical therapy in either group. This concurs with Hesse et al,[34] who suggested that muscle strength is either reflex regulated or not the prime requisite for gait improvement. In contrast, the MRC Scale, which measures muscle strength in a more general manner, revealed significant improvement during the Lokomat phases in both groups. This result should not be overrated, however, as the MRC Scale is considered to demonstrate less criterion validity than the MI.[13]

Summary

The more intensive, task-specific training provided by the Lokomat led to several better walking outcomes compared to the conventional phase of training. The electromechanical device cannot replace conventional physical therapy but may serve as an adjunct especially early after stroke and in persistently poor walkers. Operability of the Lokomat by 1 therapist alone, without a strenuous and nonergonomic workload, is a valuable advantage of Lokomat over treadmill therapy.

Optimal training strategies with individualized training programs for neurological patients need to be further developed. Then, larger randomized clinical trials are needed to establish the efficacy of Lokomat training over conventional or manually assisted treadmill strategies for the recovery of walking after stroke.

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