# Body Weight-Supported Treadmill Training after Stroke

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Gait rehabilitation is a major aspect of neurologic rehabilitation. This review focuses on locomotor therapy by treadmill stimulation with partial body weight support (BWS), which has become a very promising treatment concept over the past few years. It enables severely affected patients to follow modern aspects of motor learning, favoring a task-specific approach. Initially two therapists assist the movement, placing the paretic limbs and controlling the trunk movements. As compared with overground walking, patients walked more symmetrically, less spastically, and more efficiently on the treadmill with BWS. Several clinical controlled studies have shown its potential in patients after stroke, who regained walking ability faster in the acute or in the chronic stage. Controlled multicenter trials comparing locomotor and conventional therapy will be the next step. Also, the use of BWS during overground walking could be incorporated into the locomotor treatment program of less affected stroke patients. An electromechanical gait trainer relieving the strenuous effort of the therapists and controlling the trunk in a phase-dependent manner is a new technical alternative for severe stroke patients.

## Introduction

Restoration of gait is a major goal in neurologic rehabilitation after stroke. Three months after stroke, approximately 20% of stroke survivors remain wheelchair-bound and the walking capacity is limited in another 60% of patients [1]. To improve gait ability, therapists apply either a traditional functional approach with strengthening and practicing of single movements, or various neurofacilitation techniques, such as the Brunnstroem technique with synergistic movements, propioceptive neuromuscular facilitation with spiral and diagonal movements, and neurodevelopmental therapy (NDT, Bobath) with reflex inhibitory movements. Although different (*eg*, NDT aims at an inhibition of muscle tonus whereas the Brunnstroem concept encourages the evolvement of spasticity), none of the techniques proved superior in numerous outcome studies [2].

In Europe, the Bobath approach is most frequently applied in stroke rehabilitation. Hesse *et al.* [3] assessed gait ability and gait symmetry in 156 chronic hemiparetic patients before and after a 4-week comprehensive rehabilitation NDT program. The mean time interval after stroke was 12.8 weeks. Surprisingly, neither gait ability nor gait symmetry improved substantially. We found that tone-inhibiting maneuvers and gait-preparatory tasks during sitting and standing had prevailed, whereas gait itself was practiced very little.

Modern concepts of motor learning, however, favor a task-specific repetitive approach [4,5]. For instance, Winstein *et al.* [6] reported that balance training while standing could improve balance but not gait symmetry in hemiparetic patients. In another study, Dean *et al.* [7] instructed hemiparetic patients to train for balance while sitting by placing objects to either side on a table with their hands. At the end of the study, weight distribution between both lower limbs when sitting had improved, whereas symmetry of force distribution while standing remained unchanged. Kirker *et al.* [8] recorded the activity of the affected gluteus medius of hemiparetic patients while standing and weight shifting (as frequently practiced task within conventional treatment) and while initiating gait. The amount of activity was largest when the patients took a step with the contralateral limb, whereas the motor task during standing provoked very little activity of the paretic hip abductor. Furthermore, a recent large, Norwegian outcome study compared the Bobath program and a task-specific motor relearning program (MRP) in 61 acute stroke patients [9•]. The MRP group stayed fewer days in the hospital and their improvement in general motor functions was significantly better than in the Bobath group, confirming the concept of a task-specific repetitive approach.

## Treadmill Therapy with Partial Body Weight Support after Stroke

The favorable task-specific approach can be translated into the saying "whoever wants to relearn walking has to walk."

The concept of treadmill training combined with body weight support (BWS) for stroke patients had been suggested by Finch and Barbeau in 1986 [10]. The Berlin group has applied treadmill locomotor therapy with partial BWS in stroke rehabilitation since 1992 [11], following first reports in the successful treatment of paraparetic patients [12–14]. Several months of therapy resulted in a marked improvement of gait ability of paraparetic patients, and paraplegic patients even exhibited locomotor-like electromyographic activity of the shank muscles on the treadmill. Overground locomotor ability, however, did not change in paraplegic patients. This task-specific therapy enables hemiparetic patients to practice walking repetitively, unlike conventional treatment in which tone-inhibiting maneuvers and gait-preparatory tasks during sitting and standing dominate.

Patients wear a modified parachute harness to substitute for deficient balance, and the moving belt enforces complex stepping movements. The harness should promote a vertical position; swinging is not favorable. In case of a flexed position of the patient, it is of advantage when the point of suspension can be moved to the rear so that the trunk is more erect. A proportion of their body weight is supported by the harness, so that the patients can carry their remaining body weight adequately (*ie*, without knee collapse or excessive hip flexion during the single-stance period of the affected lower limb). The body weight is either constant with the help of servo-controlled or hydropneumatic systems throughout the gait cycle [15,16], or can vary according to the needs of the patients.

The advantages/disadvantages of the two solutions have not yet been addressed in comparative studies. The scientific background of locomotor therapy is based on experiments in adult spinalized cats and incompletely lesioned primates, showing an entrainment of spinal and supraspinal pattern generators by locomotor therapy [17]. Adult spinalized cats, which do not regain locomotor ability spontaneously, could relearn weight-bearing steps with their hindlimbs, interlimb coordination, and foot placement following a several month-long training on the treadmill with the hindlimbs partially supported. In primates, approximately 20% of the descending corticospinal pathways needed to be preserved to achieve immediate locomotion on the treadmill without a preceding training period [18].

**Technical aspects**

Patients should be able to sit at the edge of the bed independently; standing ability is not required. Cardiac risk factors, a history of recent deep vein thrombosis of the lower limbs, lower-limb joint contractures, and arthrosis can be limiting factors. Pusher syndrome is not an exclusion criteria.

Initially two (or even three) therapists are required to assist the patient's movement on the belt, so that the patient practices stepping not only repetitively, but also in a correct manner. One therapist, sitting alongside, helps with swing of the paretic limb, ensures that initial contact is made with the heel, prevents hyperextension of the knee, and controls the symmetry of steps. The second therapist, standing behind the patient, assists weight shift onto the stance limb and promotes hip and trunk extension by applying a firm pressure with the thumb on the rear of the pelvis or with the flat hand on the chest. Swinging of the patients in the harness should be strictly avoided because it prevents loading and results in continuous hip flexion. According to animal experiments, alternating loading and unloading the lower limbs and hip extension during stance are the main additional peripheral drives that can modulate the locomotor pattern [19,20]. The backward moving belt further promotes hip extension. Treadmill velocities of approximately 0.25 m/s and a BWS of no more than 30% to 40% of body weight are initially recommended. During therapy, treadmill speed should be increased and BWS reduced as soon as possible (see following) to facilitate the activity of the weight-bearing muscles and to practice cardiovascular fitness for the long term.

**Clinical and biomechanical studies**

The earliest studies (a baseline-treatment study [n=9] and two single-case design studies following an A-B-A design [n=14]) in chronic, nonambulatory hemiparetic patients revealed that the therapy was superior to conventional physiotherapy with regard to restoration of gait and improvement of ground-walking velocity [11,21,22]. The baseline treatment study with nine chronic, nonambulatory hemiparetic patients (mean stroke interval before study onset 129 days) showed no substantial improvement of gait ability during a 3-week baseline of conventional therapy. Five weeks of subsequent treadmill therapy resulted in a marked improvement of gait ability; all patients became independent walkers, at least with verbal supervision. Other motor functions improved steadily, but muscle tone and muscle strength tested while lying or sitting did not change markedly. Particularly, patients with a neglect syndrome could profit from the repetitive therapy. Albeit encouraging, this first study did not allow judging of the exclusive effects of locomotor therapy. Therefore, two single-case design studies following an A-B-A design were carried out next. During the A-phases, treadmill therapy was applied alone (n=7) or in combination with functional electrical stimulation (FES) on the belt (n=7) (*ie*, the patients did not receive any additional single physiotherapy). During the B-phases, the patients received physiotherapy of the same time extent; each of the phases lasted 3 weeks. The FES helped to facilitate the movement on the belt (*eg*, the stimulation of the N. peronaeus during the swing phase assisted the dorsiflexion of the foot). Other stimulation sites were the quadriceps (weight bearing), biceps femoris (weight bearing), and gluteus medius (pelvic stabilization) muscles. The results showed that the patients improved their gait ability and ground-level

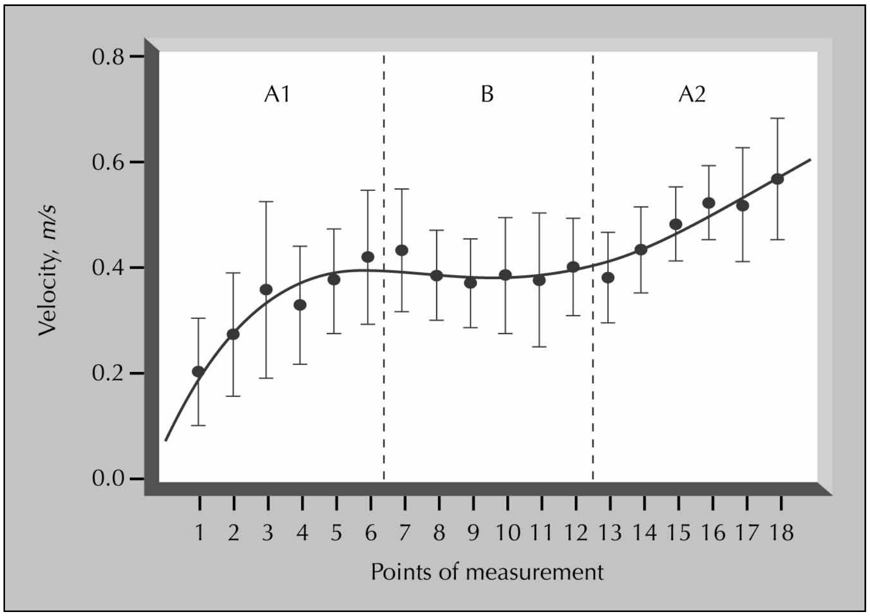



**Figure 1.** Graph shows mean walking velocity over time. Treadmill training applied during the A1 and A2 phases was more effective than physiotherapy applied during the B phase ($P$<0.05).

walking velocity considerably during the first 3-week A-phase (A1) of exclusive daily treadmill training alone or in combination with FES. During the subsequent period of 3 weeks of conventional physiotherapy, (B) gait ability did not change, whereas the second A-phase further enhanced walking ability (Fig. 1). All patients who had been wheelchair-bound before therapy became ambulatory, at least with verbal support, by the end of the study. The statistical analysis revealed a superiority of the locomotor therapy with regard to gait restoration and ground level walking velocity. During one 30-minute session of treadmill training with BWS, the patients could practice up to 1000 gait cycles as compared with a median of less than 50 gait cycles during one regular physiotherapy session. Other motor functions improved steadily, whereas the muscle tone remained unchanged. With a minimum stroke interval of 3 months before study admission, spontaneous recovery alone could have not explained the observed beneficial effects. For instance, the Copenhagen stroke study showed for their group of patients being treated in a conventional way that no substantial gait improvement occurred 12 weeks after stroke onset [22].

Next, a large Canadian study in 100 acute stroke patients compared treadmill therapy with and without BWS [24••]. Following randomization, 50 patients were trained to walk with up to 40% of their body weight supported (BWS-group), and the other 50 patients were trained to walk bearing full on their lower limbs (no-BWS group). After a 6-week training period, the BWS group scored significantly higher than the no-BWS group for functional balance ($P$=0.001), motor recovery ($P$=0.001), overground-walking speed ($P$=0.029), and overground-walking endurance ($P$=0.018) (Fig. 2). The follow-up evaluation 3 months later revealed that the BWS group continued to have significantly higher scores for overground-walking speed ($P$=0.006) and motor recovery ($P$=0.039).

The Berlin group compared treadmill therapy alone and in combination with physiotherapy in 28 chronic nonambulatory patients. Following a 3-week baseline of conventional therapy with no considerable improvement, patients either received daily treadmill therapy alone (low-intensity group) or in combination with physiotherapy focused on gait practice (high-intensity group) for a period of 3 weeks. Follow-up was 4 months later. The multivariate analysis revealed that both groups improved their gait ability considerably and that the combined approach of locomotor and physiotherapy accelerated gait restoration within the specific intervention period. At follow-up, however, group differences had waned due to a larger and continuous improvement in the low-intensity group. Gait velocity and other motor functions did not differ between the two groups at any time. The results seem to favor a more intense approach combining locomotor and physiotherapy during a defined period of time within a comprehensive rehabilitation program to accelerate the recovery of gait ability after stroke.

Most recently, Kosak and Reding [25••] published the first controlled study comparing treadmill therapy with BWS versus physiotherapy in 56 acute stroke patients. Physiotherapy included aggressive, early, therapy-assisted ambulation using knee-ankle combination bracing and hemi-bar if needed (*ie*, the approach was definitely different from classic NDT, with tone-inhibiting and gait-preparatory maneuvers dominating). Treatment sessions in both groups lasted up to 45 minutes per day for 5 days a week until patients could walk overground unassisted. Although the outcome of the two groups as a whole did not differ, a subgroup with major hemispheric stroke defined by the presence of hemiparesis, hemianopic visual deficit, and hemihypaesthesia who received more than 12 treatment sessions, showed significantly better overground endurance (90 ± 34 vs 44 ± 10 m/min) and speed scores

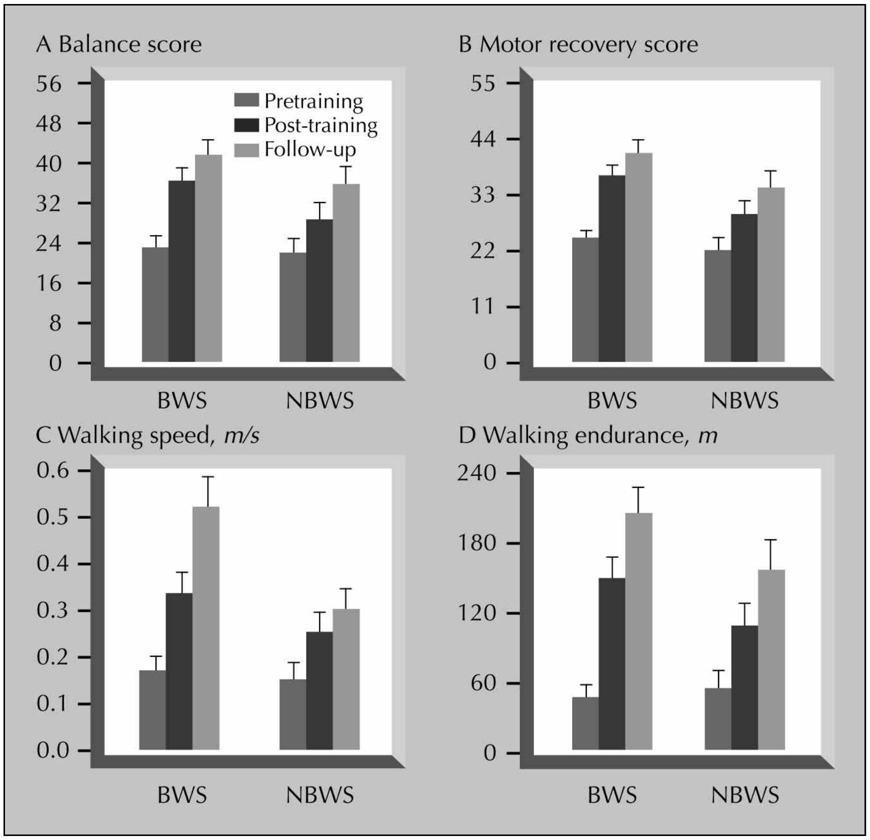


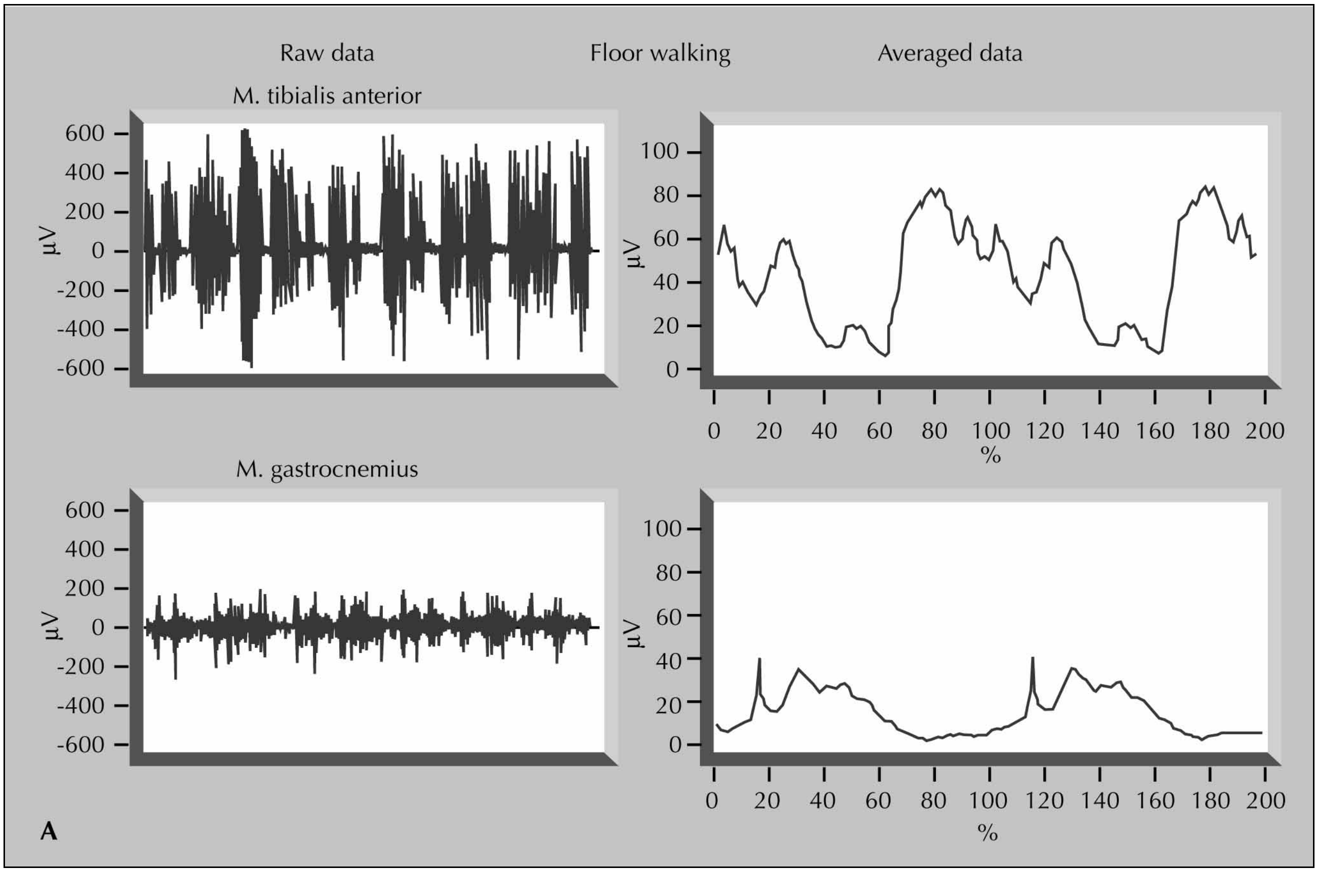

**Figure 2.** Effects of body weight–support (BWS) training on the following outcome measures: **A**, balance; **B**, motor recovery; **C**, overground-walking speed; and **D**, overground-walking endurance. Group mean scores are shown for the pretraining, posttraining, and follow-up scores. Analysis of covariance revealed significant differences for all four outcome variables between the BWS and no-BWS (NBWS) groups after training. The follow-up scores were significantly different between the two groups for motor recovery and overground-walking speed. (*Adapted from* Visintin *et al*. [24••].)

(12 ± 4 vs 8 ± 2 m/min) for the treadmill compared with the physiotherapy group. The authors concluded that both kinds of therapy were equally effective except for a subset of patients with major hemispheric stroke who were difficult to mobilize using physiotherapy alone.

Biomechanical studies documented that increasing BWS prolonged the single-stance period of the affected lower limb (thereby providing a high balance stimulus) and decreased the muscle activity of relevant weight-bearing muscles in hemiparetic patients [26]. Data suggested that BWS should not exceed 30% to 40% of body weight to optimize training of weight-bearing ability after stroke. Correspondingly, the BWS should be reduced as soon as patients are able to carry their weight on the paretic limb without abnormal postures. Clinical criteria is the patient's ability to sustain their corresponding body weight during the single-stance phase of the paretic limb adequately (*ie*, without knee collapse or swinging in the harness).

When treadmill walking with a mean of 15% BWS was compared with floor walking, hemiparetic patients walked more symmetrically [27], more dynamically, and with less spasticity on the treadmill with BWS [28•]. The relative single-stance phase of the paretic limb was significantly prolonged on the treadmill. This phase is crucial, as the paretic limb exclusively carries the load during this period of time. Consequently, a longer stance phase may have entrained effectively the weight-bearing muscles and resulted in a high-balance stimulus. Further, asymmetry of gait due to a shortened stance phase is a major feature of stroke patients. Correspondingly, a better balance on the treadmill allowed the practice of a more functional gait pattern as a generally accepted treatment goal.

Often, therapists express the fear that treadmill walking with partial BWS may provoke spasticity. The dynamic electromyogram of the shank muscles helped to assess plantarflexor spasticity as characterized by a premature activation of the soleus muscle starting in the terminal swing, and by the amount of coactivation between the soleus and tibialis anterior muscle. The results of less premature activity of the gastrocenmius and a more alternative activation pattern of the tibialis anterior muscles while treadmill walking did not confirm the often expressed fear of therapists that this technique enforces repetition of a less physiologically sound gait (Fig. 3). On the contrary, patients walked more symmetrically and less spastically during the specific intervention. Daniellson and Sunnerhagen [29•] compared oxygen consumption during treadmill walking with 30% BWS and without BWS in stroke patients. The 30%-BWS condition required less oxygen consumption than full weight bearing. The authors concluded that treadmill therapy with BWS could be tolerated by patients with cardiovascular problems. A recent study assessed the influence of walking velocity on the gait, muscle activation, and energy consumption of 25 hemiparetic patients walking on the treadmill slowly, at self-adopted, and at maximum speed [30]. A larger gait velocity on the treadmill correlated with a facilitation of relevant antigravity muscles without accompanying changes of the muscle activation



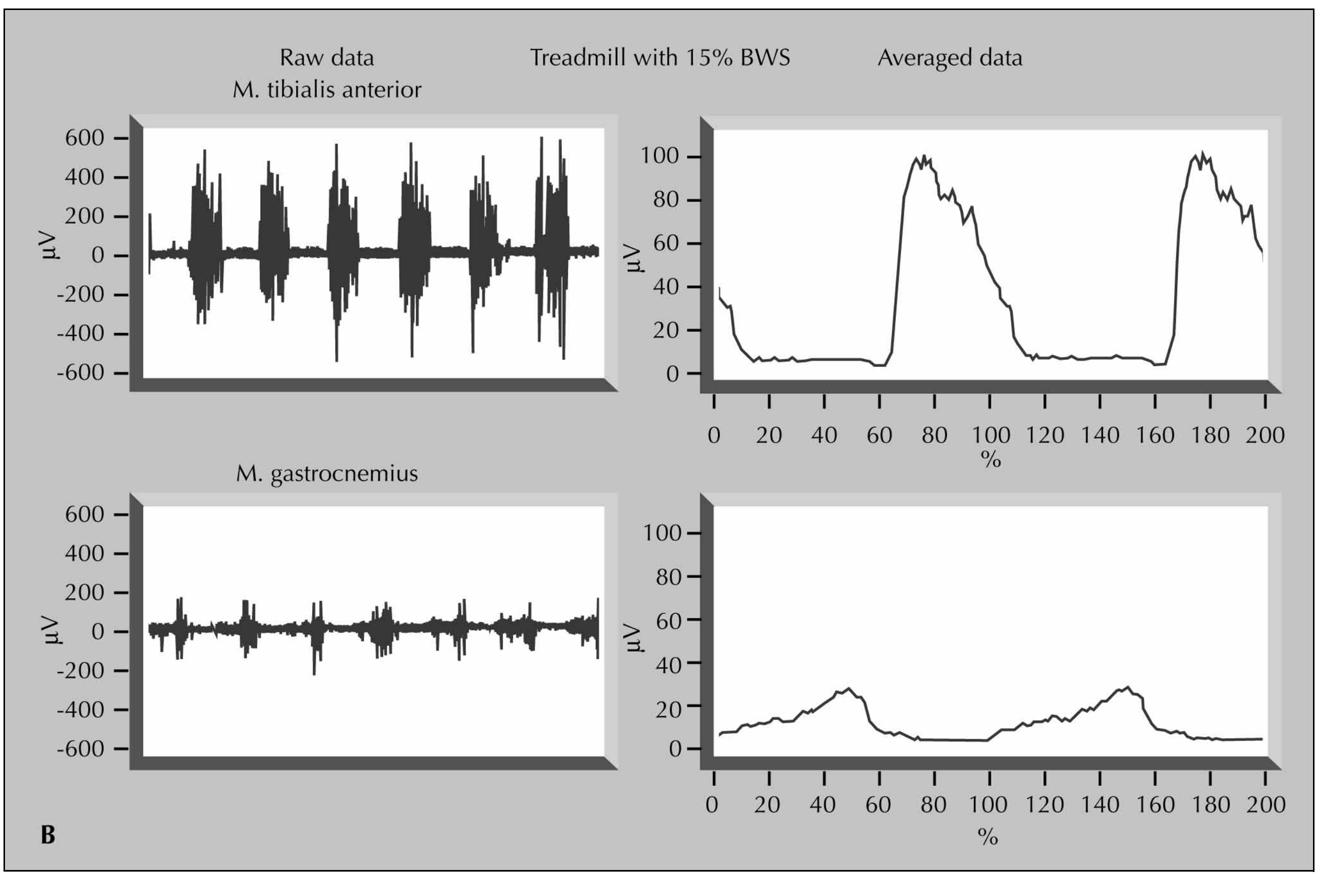




**Figure 3.** Raw and averaged data for the gait cycle-normalized activity of the left tibialis anterior and gastrocnemius muscles of a left hemiparetic patient **A**, walking on the floor and **B**, on the treadmill with 15% body weight support (BWS).

pattern. Furthermore, the patients walked more efficiently at higher velocities (*ie*, they consumed less energy per distance covered). The results encourage increasing the speed of the belt as soon as possible to facilitate the activity of relevant antigravity muscles, to economize the patient's gait, and to train cardiovascular fitness. With regard to the cardiovascular risk, the reader should keep in mind that the patients did not reach an aerobic level (mean, 2.8 mmol/L at fast speed), and that the mean maximum heart rate of 129 beats per minute was tolerable for all patients. Nevertheless, cardiovascular risk factors should be considered when training at higher belt speeds.

In a preliminary study, Macko *et al.* [31] had investigated the effect of treadmill aerobic-exercise training in nine ambulatory, chronic stroke patients [31]. They had shown that 6 months of low-intensity treadmill endurance training (three 40 minutes sessions per week walking at 50% to 60% of heart rate reserve) produced substantial and progressive reductions in the energy expenditure and cardiovascular demands of their study population.

## New Technical Developments

In considering all the advantages of this approach, some disadvantages could also be observed One of the major disadvantages of treadmill training is that it requires the effort of two or three therapists to assist the gait of severely affected patients when setting the paretic limbs and controlling trunk movements.

Therefore, our group designed and constructed an electromechanical gait trainer [32•]. The harness-secured patient was positioned on two footplates whose movements simulated stance and swing in a symmetric manner, with a ratio of 60% to 40% between stance and swing. The cadence and stride length can be set in a stepless manner within a speed range of 0.1 to 2.8 km/h, according to individual needs. A servo-controlled drive mechanism assists the gait-like movement according to the patient's abilities, and the vertical and horizontal movements of the trunk are controlled in a phase-dependent manner. Phase-dependent electrical stimulation of the quadriceps muscle during the stance phase can help to stabilize the knee; alternatively the therapist sits in front and controls the knee movement.

The sagittal joint kinematics and the dynamic electromyogram of selected lower-limb muscles in control patients have been shown to closely mimic normal gait. The ankle dorsiflexion during the swing phase was less on the gait trainer; correspondingly, the patients hit the ground not with the heel, but with the entire foot. Severely affected hemiparetic patients needed less help on the gait trainer as compared with assisted treadmill walking, although the movement was more symmetric and the single-stance phase of the paretic limb lasted longer on the gait trainer, entraining the weight-bearing muscles effectively. The dynamic electromyogram of the lower limbs revealed a comparable activation of the trunk and thigh muscles. The plantarflexor spasticity was less on the gait trainer. The activity of the tibialis anterior muscle was diminished on the gait trainer, as the patients could have put some weight on the footplate during the "swing phase," despite the controlled horizontal trunk movement.

Subsequent clinical results showed marked improvements of the gait ability of severely affected hemiparetic patients. A baseline treatment study (3 weeks of conventional therapy followed by 4 weeks of additional therapy on the gait trainer) with 14 nonambulatory hemiparetic patients (mean stroke interval 11.2 weeks) confirmed the potential of this novel approach [33]. The 4 weeks of physiotherapy and gait training resulted in a relevant improvement of gait ability in all patients. Velocity, cadence, and stride length improved significantly. The kinesiologic electromyogram of selected lower-limb muscles revealed a more physiologic pattern of the thigh and shank muscles. The confounding influence of spontaneous recovery, the lack of a control group, and the double amount of therapy were limiting factors. Further studies such as this are required.

Colombo *et al.* [34•] suggested another solution to the problem of relieving the strenuous effort from the therapists. They used a hybrid system consisting of a motor-driven treadmill (to promote the stance phase) and a powered exoskeleton with drives flexing the hip and knee during the swing phase. So far the system is purely passive, a force control sensing the patient's effort will be the next step in clinical testing. Another potential solution is a robot arm that places the limbs during their swing phases, as has been shown successfully in spinalized rats at the laboratory of Dr. Edgerton, at the University of California, Los Angeles (personal communication).

For less affected patients, Fung *et al.* [35] suggested the use of a BWS system during overground walking to promote the transfer of treadmill to overground speed. The effect of partial weight support during overground walking improved force generation, postural alignment, and lower limb movement in a group of 14 stroke patients.

## Conclusions

Treadmill therapy with partial BWS is a promising new approach to promote gait ability after stroke. The task-specific approach enables wheelchair-bound patients the repetitive practice of complex gait cycles instead of single gait-preparatory maneuvers. Patients walk more symmetrically, less spastically, and more efficiently on the treadmill as compared with floor walking. The earliest controlled clinical studies showed the potential of treadmill therapy with partial BWS; multicenter trials comparing treadmill and conventional therapy will be the next step. Also, the use of BWS during overground walking shows great potential for less affected patients. The electromechanical gait trainer is a further technical development to ease the therapist's effort, for instance, when setting the paretic limbs or controlling the trunk movements of severely affected patients.

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