

Gait Training of Patients After Stroke Using an Electromechanical Gait Trainer Combined With Simultaneous Functional Electrical Stimulation

Background and Purpose. This case report describes the implementation of gait training intervention that used an electromechanical gait trainer with simultaneous functional electrical stimulation (FES) for 2 patients with acute ischemic stroke. **Case Descriptions.** Two individuals with post-stroke hemiplegia of less than 6 weeks' duration participated in a 4-week gait training program as an adjunct to physical therapy received at a hospital. After the 4-week intervention, both patients were discharged from the hospital, and they returned after 6 months for a follow-up evaluation. **Outcomes.** By the end of the 4-week intervention, both patients had shown improvements in scores on the Barthel Index, Berg Balance Scale, Functional Ambulation Categories Scale, 5-m timed walking test, and Motricity Index. In the 6-month follow-up evaluation, both patients continued to have improvements in all outcome measures. **Discussion.** This case report shows that, following the use of an electromechanical gait trainer simultaneously with FES, patients after acute stroke had improvements in gait performance, functional activities, balance, and motor control in the long term. [Tong RKY, Ng MFW, Li LSW, So EFM. Gait training of patients after stroke using an electromechanical gait trainer combined with simultaneous functional electrical stimulation. *Phys Ther*. 2006;86:1282-1294.]

Key Words: *Cerebrovascular accident, Electrical stimulation, Gait, Rehabilitation, Stroke.*

Raymond KY Tong, Maple FW Ng, Leonard SW Li, Elaine FM So

This case report describes the combined use of functional electrical stimulation with a gait trainer in a gait training protocol to generate active movement in patients' paralyzed lower-limb muscles.

In general, gait is greatly altered after people are affected by a stroke. More than half of patients in the acute phase after stroke are not able to walk, and walking impairments are still present 3 months after stroke.^{1,2} Greater effectiveness in gait training has become one of the goals in post-stroke neurological rehabilitation. Early physical therapy intervention in gait training is believed to be beneficial for patients after a stroke.³ For 197 elderly patients after hemiplegic stroke, Friedman⁴ showed that almost all of the patients who had attained the ability to ambulate independently by day 7 were more likely to maintain gait independence in the few months afterward than those who could not walk without human assistance by day 7.

Early, intensive, and gait-focused training has been shown to be effective in some studies of ambulatory ability in patients after stroke.^{3,5-6} These studies indicated that repetitive, task-oriented (ie, gait-focused) exercise programs improved functional capabilities in people with neurological deficits. However, conventional gait training alone, without the use of other interventions such as body weight support (BWS), often leads to an asymmetrical gait pattern in many patients after stroke.⁷ One study⁸ showed that bone loss in the lower femoral neck on the paretic side was related to when the patients relearned to walk after stroke as well as to asymmetrical weight bearing when standing. Moreover, bone adaptation was driven by dynamic loading rather than static loading, and the influence of weight bearing on the paretic leg during walking may be important to prevent bone loss. Treadmill ambulation training with support of a percentage of the patient's body weight to reduce the load on the legs has been developed to provide controlled gait weight shifting, balance, and stepping.⁹ In their studies of patients who

had sustained acute strokes less than 6 weeks earlier, da Cunha and colleagues^{10,11} concluded that body weight-supported treadmill ambulation training is a feasible and safe technique and has a promising role to play in gait training.

Treadmill training, however, has several disadvantages. Kosak and Reding¹² stated that the physical therapists in their study preferred patient rehabilitation involving floor walking with aggressive bracing over treadmill walking alone, because gait training on a treadmill requires 2 or 3 therapists to assist with setting the paretic limb and controlling the trunk movements, especially in patients who are severely affected by stroke. In order to reduce therapists' efforts, Hesse and colleagues¹³ developed an electromechanical gait trainer (GT II*) that enabled patients who were unable to walk independently to practice a gait-like movement with minimal human assistance. The main feature of this electromechanical gait trainer was the simulation of stance and swing, with a ratio of 60%/40% between stance and swing phases. This ratio was based on normal walking speed, and the aim of the rehabilitation was to train the patients to walk with a normal gait pattern by the end of the training. On

* Reha Stim, Kastanienalle 32, 14050 Berlin, Germany.

RKY Tong, PhD, is Assistant Professor, Department of Health Technology and Informatics, Hong Kong Polytechnic University, Hung Hom, Hong Kong. Address all correspondence to Dr Tong at: k.y.tong@polyu.edu.hk.

MFW Ng, PT, is a student in the Department of Health Technology and Informatics, Hong Kong Polytechnic University.

LSW Li, MD, is Director, Rehabilitation Unit, and Consultant Physician in Rehabilitation Medicine, Tung Wah Hospital, Hong Kong.

EFM So, PT, is Department Manager, Department of Physiotherapy, Tung Wah Hospital.

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the gait trainer, only minimal help from the therapist was needed for shifting weight onto the stance limb, whereas hip extension was achieved mainly by the moving footplates. In case reports^{14,15} and a randomized crossover study¹⁶ by Hesse and colleagues, the gait trainer was shown to be an effective alternative in intense post-stroke gait rehabilitation to treadmill therapy with partial BWS in terms of improvement in gait performance and walking speed. Hesse and colleagues also stated that the advantages of using the gait trainer for rehabilitation were a reduction in effort by physical therapists and a more independent and highly symmetrical walking pattern for patients who are nonambulatory.

In this case report, we describe the combined use of functional electrical stimulation (FES) with a gait trainer in a gait training protocol to generate active movement in patients' paralyzed lower-limb muscles. Functional electrical stimulation has been shown to have therapeutic benefits in the early phase of gait rehabilitation, enabling patients with brain injuries to achieve a better functional result in a shorter period of time.^{17,18} Although FES and the use of a gait trainer have been separately demonstrated to have positive therapeutic effects in post-stroke rehabilitation, both techniques have never been applied in the same study of stroke recovery. Current theories of perceptual learning and recovery of function in people with brain damage recommend that meaningful, graded stimuli with active participation (ie, sensorimotor coupling) and accurate feedback should be applied.^{19,20}

Because the therapeutic effects of using a gait trainer coupled with simultaneous FES have not yet been studied in patients after acute stroke, the purpose of this case report is to describe and discuss the gait training and performance details of 2 patients who underwent combined FES and gait training intervention in their rehabilitation, with a focus on the application of daily FES-gait training intervention sessions and follow-up methods.

Case Description

Two patients were recruited to examine the feasibility and effects of using the gait trainer with FES in the rehabilitation of patients with acute stroke.

Patient A

Patient A (male, 75 years of age) was affected by a first-time ischemic stroke in the mid-pontine region and the left centrum semiovale with right-sided hemiparesis. His body weight was 57 kg, and his height was 162 cm. He was a former smoker and had a history of gout, and he had been newly diagnosed with hypertension and diabetes mellitus. He was totally independent in all activities of daily living (ADL) before the onset of stroke.

After stroke, before beginning the 4-week intervention program, he was only able to turn over in bed and unable to rise from bed without assistance, he could not maintain his balance when sitting up or standing, and he tended to lean on his right side. His Berg Balance Scale (BBS) score was 4 out of 56, which indicated a high risk for falling. He was totally dependent on others for all self-care needs (Barthel Index [BI] score=10), which were complicated by urine retention and a urinary tract infection. His total Motricity Index leg score was 59 out of 100. No increase in muscle tone (velocity-dependent resistance to stretch) was found in the limb muscles, and there was no loss in sensation. He could not communicate well verbally because he was affected by left facial nerve palsy, which slurred his speech. However, his score on the Mini-Mental State Examination (MMSE) at admission was 22 out of 30, which indicated that he had enough cognitive ability to understand our instructions and explanations of the intervention protocol.²¹ His main difficulties were controlling the placement of his paretic lower extremity, controlling his trunk in a midline orientation, and balancing.

Patient A had received daily physical therapy, occupational therapy, speech therapy, and sessions with a psychologist for 2 weeks before being admitted into our gait training program. The physical therapy consisted of regular, weekday 40-minute sessions of training based on the principles of proprioceptive neuromuscular facilitation and the Bobath concept, with the sessions conducted by the patient's therapist in the hospital's physical therapy department. The Bobath treatment aimed to improve the patient's posture and movement. In addition, patient A received 1.5-hour multidisciplinary treatment sessions, which comprised occupational therapy, speech therapy, and psychological consultations. The time between patient A's onset of stroke and admission to our gait training program was 4 weeks. His lower-limb motor power and balance did not change considerably in the first 4 weeks after stroke. Before the gait training intervention, he could walk at a speed of 0.09 m/s (Functional Ambulation Categories [FAC] scale level 1) with the assistance of one physical therapist providing firm, continuous support for balance and placement of the paretic limbs. Limited knee flexion on the affected side was observed during the single-leg stance and swing phases of gait. Right hip extension decreased at the end of the stance phase. Step length and single-leg support time were shorter than for the unaffected side.

The inclusion criteria for this program were that the individual had to have normal communication and cognitive skills and a moderate to severe ambulatory deficit (FAC scale level <3) within 6 weeks of the first unilateral stroke. Patient A met the criteria, and he gave his informed consent to take part in the gait training

Table 1.Summary of Outcome Measurements^a

	Patient A			Patient B		
	Before Intervention (Baseline)	After 4-Week Intervention	6-Month Follow-up	Before Intervention (Baseline)	After 4-Week Intervention	6-Month Follow-up
BI (maximum score=100)	10	40	75	35	60	90
BBS (maximum score=56)	4	30	42	16	40	50
FAC (maximum score=5)	1	3	4	1	3	5
MI leg score (maximum score=100)	59	92	84	38	48	78
Hip	19	25	25	14	14	25
Knee	14	33	25	14	19	33
Ankle	25	33	33	9	14	19
Walking speed over 5 m (m/s)	0.09	0.33	0.35	0.08	0.31	0.56

^a BI=Barthel Index, BBS=Berg Balance Scale, FAC=Functional Ambulation Categories scale, MI=Motricity Index.

program. The gait training program was approved by the Institutional Review Board of Hong Kong Polytechnic University. Outcome measurements of patient A were taken before the 4-week gait training intervention commenced and are shown in Table 1.

Patient B

Patient B (male, 59 years of age) was affected by a first-time ischemic stroke (right pontine infarct) with left-sided hemiparesis. His body weight was 54.5 kg, and his height was 164 cm. Prior to the stroke, he had been an independent, retired construction worker. He was a chronic smoker and had a history of gout, pneumoconiosis, and pulmonary tuberculosis. He was independent in all ADL before being affected by the stroke. After the stroke, he had received conventional treatment from the hospital for 3 weeks before being admitted to our gait training program. The time between the stroke and admission to the gait training program was 4 weeks. He could sit unsupported but required help during transfers and standing. The muscle tone of the left wrist flexor, elbow flexor, and plantar flexor were increased to 1 on the modified Ashworth scale. Sensation in the foot and shank was normal using the sharp/blunt discrimination test.

During walking, he needed continuous support by a physical therapist to help with limb placement, balance, and weight bearing (FAC scale level 1). His maximum walking distance was about 7 m, and his walking speed was 0.08 m/s (Tab. 1). His affected left upper limb was paralyzed and without motor control, and his left lower limb had weakness with a Motricity Index leg score of 38 (lack of motor control on the left ankle). He needed major help in all self-care activities, but he was continent (BI score=35). He had a high risk for falling, as indicated by a BBS score of 16. Observational gait analysis was performed as the patient walked with a quadripod at

a self-selected pace with continuous support from a therapist for fall prevention. He had left knee hyperextension during the left stance phase in order to preserve stability during weight bearing, and equinovarus with the foot drop dragging during the left swing phase. He had hip hiking and circumduction compensation maneuvers of the contralateral limb during the left swing phase because of the insufficient foot clearance in the mid-swing phase due to a lack of ankle dorsiflexion. He also had poor left knee control, probably because of quadriceps femoris muscle weakness. His gait and mobility were disturbed occasionally by the clonus reflex of the left ankle plantar flexor when the affected calf muscles (gastrocnemius and soleus) were stretched suddenly during movement. In this situation, patient B had to stop walking and wait for the clonus to diminish. His cognitive condition was sufficient (MMSE score=24/30) to understand the gait training program's instructions and purposes. He satisfied the inclusion criteria for participation in the program, and he gave his informed consent to be involved.

Assessment Tools

The functional level of each patient after stroke was evaluated in terms of independence in ADL, balance, ability in ambulation, overground walking speed, and motor impairment. The outcome parameters were evaluated on 3 occasions by a physical therapist who was registered with the Physiotherapists Board of Hong Kong: 1 day before the commencement of the 4-week FES-gait training intervention program, 1 day after the 4-week intervention finished, and 6 months after the end of the intervention. The 2 patients were to be discharged from the hospital after completing the 4-week intervention.

If the patients gained independence in ambulation from the intervention, then they also may have gained more

Table 2.Functional Ambulation Categories Scale²⁶

0	Patient cannot ambulate, ambulates in parallel bars only, or requires supervision or physical assistance from more than one person to ambulate safely outside of parallel bars.
1	Patient requires manual contacts of no more than one person during ambulation on level surfaces to prevent falling. Manual contacts are continuous and necessary to support body weight as well as maintain balance or assist coordination.
2	Patient requires manual contact of no more than one person during ambulation on level surfaces to prevent falling. Manual contact consists of continuous or intermittent light touch to assist balance or coordination.
3	Patients can physically ambulate on level surfaces without manual contact of another person but for safety requires standby guarding of no more than one person because of poor judgment, questionable cardiac status, or the need for verbal cueing to complete the task.
4	Patient can ambulate independently on level surfaces but requires supervision or physical assistance to negotiate any of the following: stairs, inclines, or nonlevel surfaces.
5	Patient can ambulate independently on nonlevel and level surfaces, stairs, and inclines.

independence in everyday activities such as self-care; therefore, we used the BI to assess the patients' performance of ADL. The BI covers actions such as walking, dressing, going to the toilet, and continence, in which a score of 100 represents independence and 0 represents total dependence. The BI has been shown to be a reliable (Cronbach $\alpha \geq .84$), valid (FIM motor subscale versus BI: Spearman correlation coefficient $\geq .92$), and responsive (FIM motor subscale versus BI: change score = 0.88) measure of basic ADL in patients after stroke.²² Balance was assessed with the BBS, which is an ordinal measure of balance performance. The BBS has been shown to yield data with excellent interrater and intrarater reliability in elderly subjects²³ and in subjects after stroke (interrater intraclass correlation coefficient [2,1] = .98 and intrarater intraclass correlation coefficient [2,1] = .97).²⁴ The BBS has been used to predict falls in elderly people in previous studies^{22,23} and was able to detect changes in status of patients after stroke.²⁵

We measured the patients' gait performance using the FAC scale (Tab. 2).²⁶ The 6-point FAC scale is designed to assess a person's ability to walk, regardless of whether an assistive device is used, and the score is based on the amount of support needed. The patients were asked to stand and take some steps if possible, and their gait performance was scored on the FAC scale (kappa = .85 for interrater comparisons²⁷). Motor function was measured using the Motricity Index leg score, which has a score range of 1 to 100. The leg score for a patient comprised 3 joint movements (hip flexion, knee extension, and ankle dorsiflexion) and was used for analysis of motor loss of the paretic lower limb after stroke. Validity and reliability have been shown on patients after stroke

(Cronbach alpha = .77, Pearson correlations between Motricity Index scores and dynamometer scores = .78–.91).^{28–30} In all of these assessment scales, a higher number represents a higher degree of motor function and muscle strength (force-generating capacity).

Overground walking speed was evaluated by timing a 5-m walk with a stopwatch, with 1 m before and 1 m after the 5-m region untimed for the acceleration and deceleration phases of each patient. Walking speed was calculated in meters per second. Both patients were asked to walk as fast as possible on a measured walkway, with any assistive aids if necessary and whatever assistance required from a physical therapist. The walking test was conducted twice, with the average walking speed of the 2 trials used for further comparison. The 5-m walking test was designed by da Cunha et al¹⁰ for people with recent strokes, with the short distance enabling people with relatively poorer aerobic fitness, balance, and lower-limb strength to complete the test more readily. Because spasticity in a lower limb or upper limb can affect a person's stability and balance during walking, we used the modified Ashworth scale to measure muscle tone (kappa = .84 for interrater comparisons and .83 for intrarater comparisons on patients with acute stroke³¹). The knee, ankle, wrist, and elbow ranges of motion were graded from 0 to 5, with 0 representing no increase in muscle tone and 5 representing rigid flexion or extension. Sensation was evaluated by the sharp/blunt discrimination test on the foot and shank segments.

Intervention

The 4-week gait training intervention that patient A and patient B underwent separately comprised a 20-minute training session every day from Monday to Friday on the electromechanical gait trainer coupled with simultaneous FES, with optional rest breaks after 10 minutes if the patients requested any. The patients stayed in the hospital during the 4-week intervention of a total of 20 training sessions. During this period, they also received 40-minute sessions of physical therapy and 1.5-hour sessions of the multidisciplinary rehabilitation program.

The gait trainer was designed by Werner and colleagues¹⁶ to simulate gait phases in a symmetric manner with a ratio of 60% to 40% between the stance and swing phases. This ratio was based on normal walking speed, and the gait training was aimed at training patients after a stroke to attain as close to a normal gait pattern as possible by the end of their rehabilitation programs.

The gait trainer supported each patient via a harness attached to ropes, which were in turn connected to a gearing system that was adjusted according to the patient's ability in lifting each foot during the swing phase. Pulleys supported part of the body weight

Table 3.

Functional Electrical Stimulation Parameters During 4-Week Intervention

	Quadriceps Femoris Muscle	Common Peroneal Nerve
Stimulation phase	Stance phase	Swing phase
Stimulation frequency (Hz)	40	40
Pulse width (μs)	400	400
Rising edge ramp (s)	0.3	0.3
Falling edge ramp (s)	0.3	0.3
Waveform	Rectangular pulse	Rectangular pulse
Extension (s)	0.1	0.1
Current (mA)	50–85	50–70

through the harness-secured system. The harness-secured patient was positioned upright with each foot placed on a footplate, and the propulsion of the footplates helped the movement of the legs and feet during the stance and swing phases. Furthermore, the gait trainer assisted in weight shifting and keeping the trunk erect by controlling the horizontal and vertical movements of the center of mass.¹⁶ The strategy was to get the patient walking in an upright posture with proper limb alignment and proper weight shifting and weight bearing, especially by the paretic lower limb during the loading response phase and the mid-stance phase. In our gait training program, step length and walking speed could be adjusted from 34 to 48 cm and from 0 to 0.70 m/s, respectively. Other training variables included the percentage of partial BWS and the use of the gait trainer's front horizontal bar for hand support by the patient to increase stability. The target training gait speed was relatively slow (0.20–0.60 m/s) to avoid overexerting the patient.³² Body weight was partially supported by the harness to compensate for the paresis of the affected lower limb, and this relief was reduced as soon as the patient could support more of his body weight. The clinical criteria were that the patient have the ability to extend his hips and that the patient have the ability to carry his body weight sufficiently on the affected lower limb. Additional physical therapist help was available during the gait training according to the patient's needs (eg, for correcting hyperextension of the paretic knee during the stance phase). If a patient achieved adequate balance while on the gait trainer, he then was trained not to grasp the front horizontal bar in order to further exercise his balance and postural control for walking.

While on the gait trainer, each patient received electrical stimulation modalities such as waveform and pulse width with fixed values and with only the stimulation intensity adjusted (50–85 mA for the quadriceps femoris muscle, 50–70 mA for the common peroneal nerve) by the supervising physical therapist, according to the patient's

needs at different stages of recovery (Tab. 3). A pair of self-adhesive electrodes (PALS 5- × 5-cm square electrodes, model Platinum Blue 901220)[†] were attached over the patient's quadriceps femoris muscle on the paretic side and stimulated in the stance phase to facilitate weight acceptance. Another pair of electrodes (PALS 38-mm round electrodes, model Ultraflex 881150)[†] were attached over the patient's common peroneal nerve on the paretic side and stimulated during the swing phase to generate ankle dorsiflexion and knee flexion. The stimulation sites were

determined while the patient was in a seated position and until a correct functional response was obtained. The patient's knee was extended when the quadriceps femoris muscle was stimulated, and the patient's ankle was dorsiflexed when the common peroneal nerve was stimulated. Stimulation intensity was increased until the functional movement over the required range of motion (knee angle less than 20° from full extension, ankle in neutral or doriflexed position) was achieved but the patient still felt comfortable with the stimulation sensation, and the sites then were marked on the skin with nonconductive, semipermanent ink. Electrodes were attached to the same marked sites throughout the 4-week intervention. Intermittent electrical stimulation then was tested continuously for at least 10 minutes before the first training session started in order to rule out skin allergy contraindication.

Figure 1 shows one patient on the gait trainer with 2 pairs of electrodes attached to the paretic lower limb. Excessive stimulation at the beginning could cause discomfort or disturb the patient instead of providing assistance. Therefore, the physical therapist gradually increased the intensity until the functional responses from the stimulated muscles were observed and the patient still felt comfortable with the stimulation sensation. When a training session started, the amplitudes of the stimulating pulses were raised to the predefined stimulation intensities that induced the required ranges of motion while still being comfortable for the patient. Caution was practiced on electrode placement because the muscle response from FES in a standing position may be different from that in a seated position, and placement of electrodes was adjusted to take this into account. Two connection wires linked the gait trainer control box and the 2 single-channel FES stimulators (model R01-0093[‡]) that were developed to synchronize

[†] Nidd Valley Medical Ltd, Knaresborough, United Kingdom.

[‡] Jockey Club Rehabilitation Engineering Centre, The Hong Kong Polytechnic University, Hong Kong SAR, China.



Figure 1.

One of the patients on the electromechanical gait trainer wearing 2 functional electrical stimulation (FES) devices. Electrodes were attached over the quadriceps femoris muscle and the common peroneal nerve of his paretic lower limb.

between the gait phases and the stimulation timing for the quadriceps femoris muscle and the common peroneal nerve. The therapist assisted the patient on the gait trainer in knee extension according to need and provided verbal cueing to facilitate the patient's keeping his head and trunk in an upright position. The patient also needed to be aware of the midline orientation of his posture in case he leaned to his paretic side or increased kyphosis during a session. Figures 2 and 3 show the paretic lower limb in the sagittal plane together with the gait trainer footplate during the stance and swing phases of one gait cycle, which was synchronized with the FES pattern.

Blood pressure was measured before and after each session for monitoring of the patient's health condition. Guidelines for cessation of intervention included complaints of headache, confusion, onset of angina, and excessive blood pressure before and during training (systolic blood pressure greater than 220 mm Hg, diastolic blood pressure greater than 110 mm Hg). Upon request from the patient, a rest break for fatigue was

allowed after 10 minutes into a session. A daily log sheet was kept to record measurements of blood pressure, heart rate, gait speed generated by the gait trainer, percentage of BWS by the harness, total distance walked, and number of rests during the session.

Patient A

Patient A received gait training with simultaneous FES for 4 weeks, with one session per weekday for 20 minutes each session. For the first 10 sessions, he put on the harness while in a wheelchair positioned in front of the gait trainer and was transferred onto the gait trainer with the help of a quadripod and 2 physical therapists. While he was seated on a foldable chair, his feet were then secured to the adjustable footplates with Velcro straps,[§] and pairs of self-adhesive surface electrodes were put on the quadriceps femoris muscle and the common peroneal nerve on the affected side. Patient A then stood up with the help of the pulley system, and the gait training started at a speed of 0.14 m/s, step length of 45 cm, and 5.3% BWS. One therapist sat in front of the patient to further stabilize the affected knee during the single-leg stance phase. The patient completed the 20-minute training sessions without requesting a rest break. At the end of each session, he was transferred back to his wheelchair with the help of the pulley system. After 10 sessions, he was able to step onto the gait trainer with the help of one therapist and then put on the harness by holding on to the front horizontal bar.

Patient A completed 19 out of 20 possible sessions over the 4-week intervention period. One session was not undertaken because of the patient's schedule conflict with a medical assessment. Intervention details of each session are listed in Table 4. Patient A progressed gradually, with a reduction in BWS and an increase in gait speed, which are plotted in Figures 4 and 5, respectively. The initial set walking speed on the gait trainer was 0.14 m/s, and the speed was steadily increased to 0.34 m/s toward the end of the 4-week period. Body weight support decreased from 5.3% on day 1 to 0% on day 15, by which time he had demonstrated he could bear his body weight on both legs when walking on the gait trainer. Other observable progressions during the sessions were more coordinated trunk control and a decrease in holding the front horizontal bar for support. On day 10, he was able to walk with one hand on the horizontal bar for support; on day 16, he had continuously progressed to walk without any hand support. After day 16, he began walking with an upright trunk and arm swings; by the last session, he was able to walk independently on the gait trainer with FES.

[§] Velcro USA Inc, 406 Brown Ave, Manchester, NH 03103.

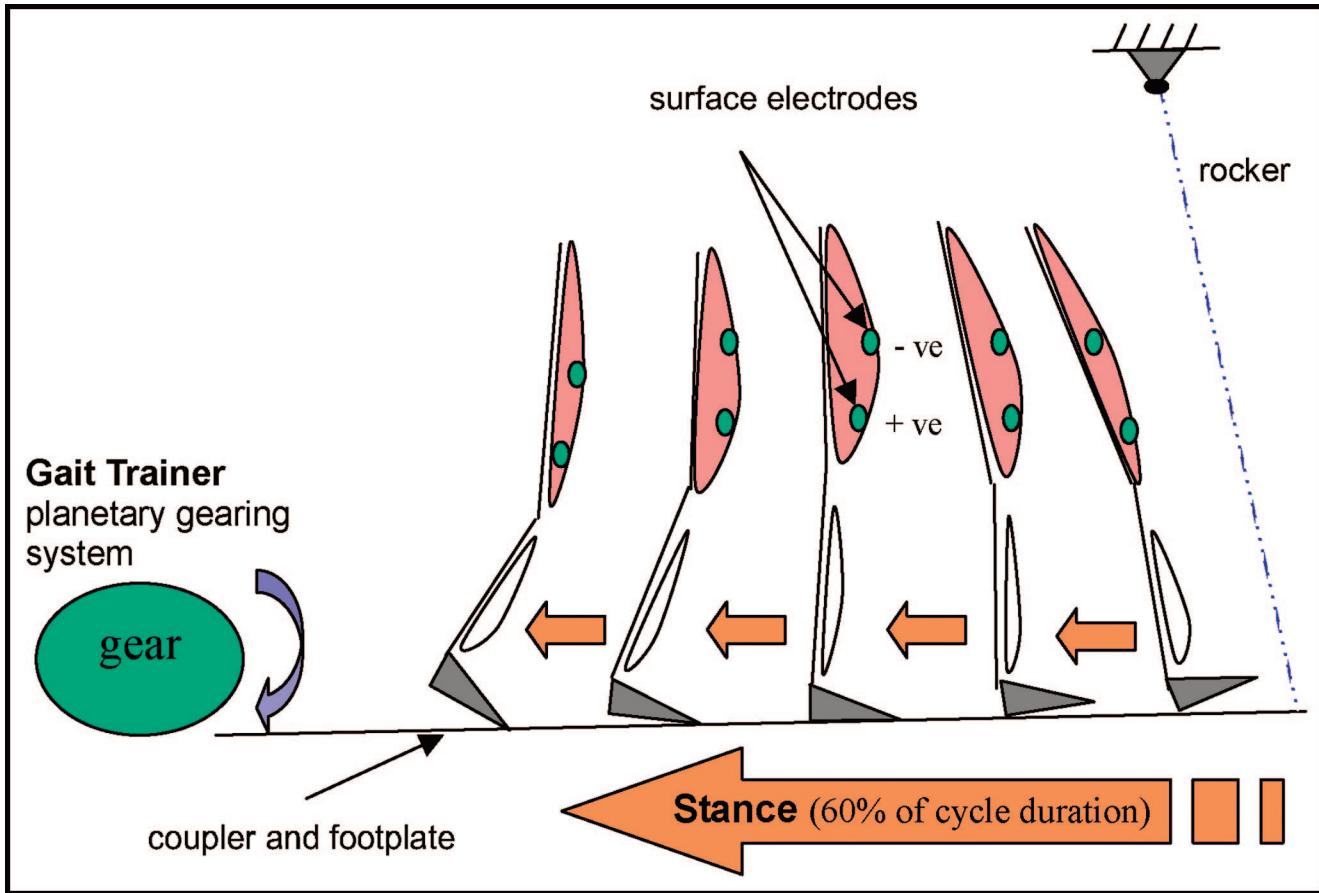


Figure 2.

Position of the paretic leg (sagittal plane) on the gait trainer footplate during a stance phase. The colored muscle represents the quadriceps femoris muscle that was stimulated during the stance phase. The “-ve” and “+ve” represent the positions for the active electrode and the indifferent electrode, respectively.

Patient B

Patient B received the same intervention protocol on the gait trainer with FES as patient A. He underwent 18 sessions of intervention over the 4-week period. Two sessions were not undertaken because of a schedule conflict with an appointment for a phenol block injection to his left calf muscles for clonus reflex control on day 11 and an appointment with a clinical psychologist on day 18. Intervention details of each session are listed in Table 5. Patient B showed large improvements during the first week's sessions in terms of an increase in gait speed and reduced BWS. His progress for the 4-week period in terms of BWS and walking speed is shown in Figures 4 and 5, respectively. Body weight support decreased from 13.0% on day 1 to 1.8% at the last session, and gait speed increased from 0.17 to 0.31 m/s during the 4-week period. Patient B was short of breath during the first 5 sessions, probably because of his past history of pneumoconiosis. The relatively high number of rest breaks he requested as well as termination prior to completion of each 20-minute session (Tab. 5) indicated poor exercise endurance. He also said that his left calf muscles were painful and swollen after his phenol

block injection on day 11, and he developed gout on day 16, which manifested in a slight increase in BWS and a reduction in gait speed on days 12 and 16. Nevertheless, he had made overall progress by the end of the 4-week intervention, and in his last session was able to walk independently on the gait trainer with FES without holding the front horizontal bar for support.

Outcomes

Patient A

After the 4-week intervention, patient A said he was more confident in overground walking and more aware about his midline orientation and upright trunk posture. His balance, functional mobility, and ambulation ability had improved, as indicated by all measurements (Tab. 1). He was able to walk overground with a quadripod and with minimal assistance from a physical therapist. His maximum walking distance and gait speed on an indoor floor were 160 m and 0.33 m/s, respectively. His balance in standing had improved, and he could stand with his legs shoulder width apart without physical assistance for more than 2 minutes under supervision. His dynamic

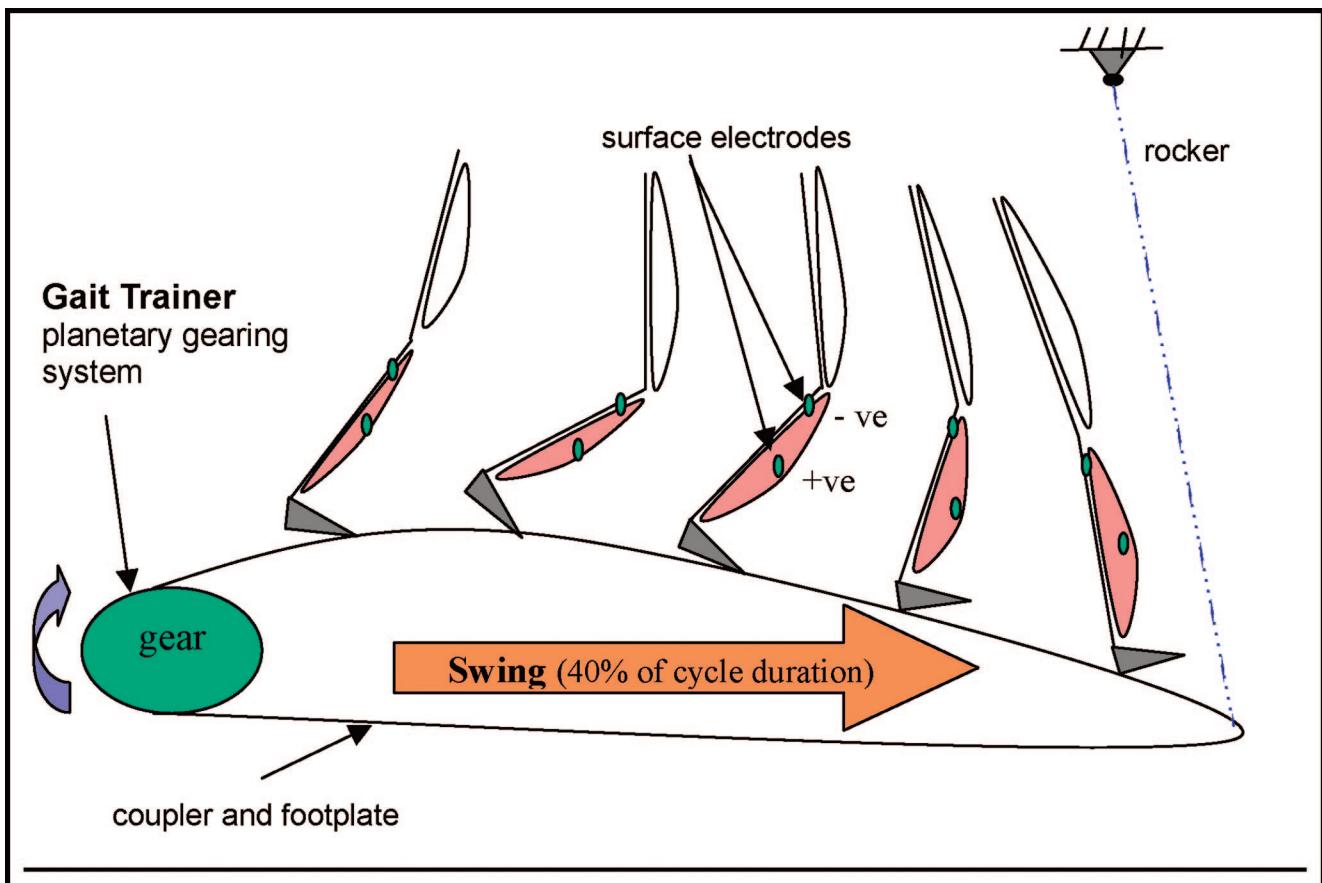


Figure 3.

Position of the paretic leg (sagittal plane) on the gait trainer footplate during a swing phase. During the swing phase, the common peroneal nerve was stimulated. The colored muscle represents the tibialis anterior muscle that was activated after stimulation. The “-ve” and “+ve” represent the positions for the active electrode and the indifferent electrode, respectively.

Table 4.

Patient A: Daily Record of Intervention Sessions

Day	Body Weight Support (%)	Gait Speed (m/s)	No. of Rest Breaks	Total Distance Walked (m)	Total Session Time (min)
1	5.3	0.14	0	235	20
2	7.0	0.20	0	248	18
3	7.0	0.20	0	284	20
4	5.3	0.20	0	279	20
5	1.8	0.22	0	282	17
6	5.3	0.22	0	302	20
7 ^a					
8	5.3	0.22	0	326	21
9	5.3	0.22	0	330	20
10	5.3	0.22	0	310	18
11	5.3	0.25	0	347	20
12	5.3	0.25	0	360	21
13	3.5	0.25	0	350	20
14	1.8	0.28	0	380	20
15	0	0.31	0	390	18
16	0	0.31	0	400	21
17	0	0.31	0	360	18
18	0	0.31	0	395	20
19	0	0.34	0	385	20
20	0	0.34	0	430	20

^a No data because of a missed training session due to a conflicting scheduled medical assessment.

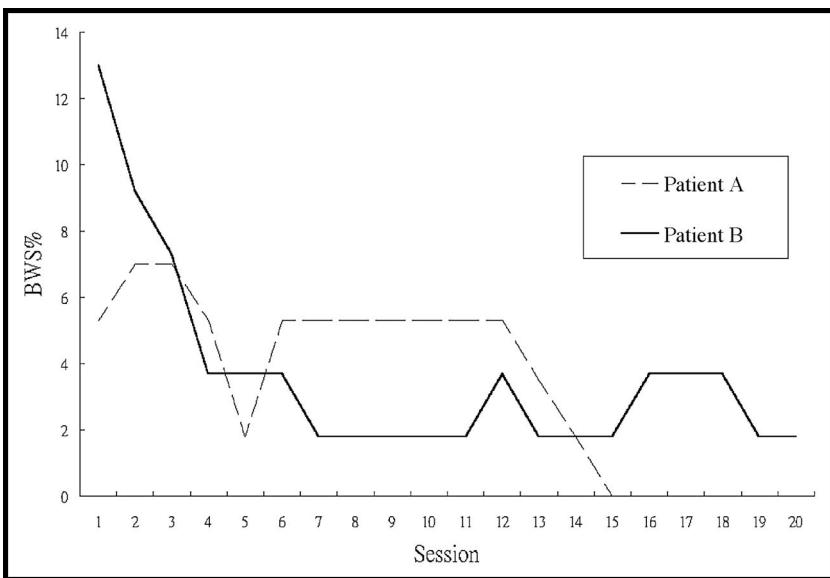


Figure 4.

The percentage of body weight support (BWS%) given in the 20 sessions of intervention to the 2 patients in the gait training program.

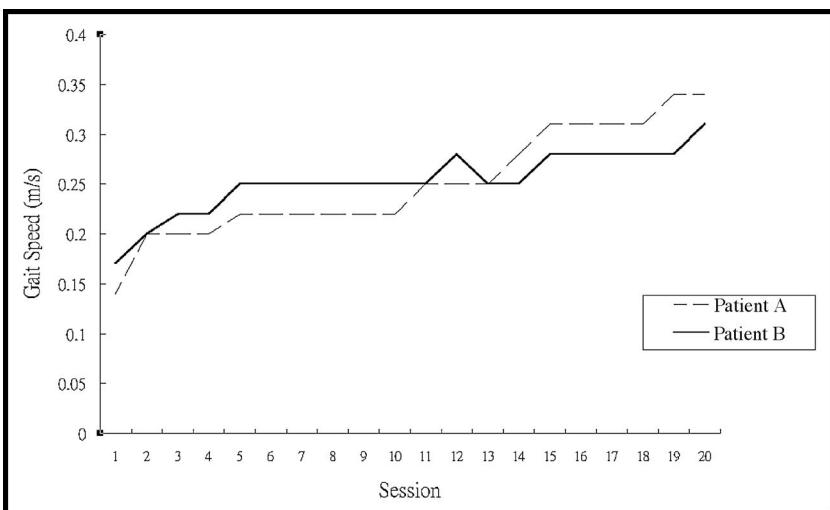


Figure 5.

Walking speed in the 20 sessions of intervention by the 2 patients in the gait training program.

balance also was better, and he could pick up a pen in front of him from the floor as well as reach forward under supervision. He became partially independent in self-care and required only a little help when putting on shoes and buttoning and unbuttoning clothing. He was fully continent (BI score=40).

We asked patient A to return for a follow-up assessment 6 months after the end of the FES-gait training intervention and discharge from the hospital (Tab. 1). He had received approximately 48 hours of postdischarge physical therapy and occupational therapy in a day rehabilitation center after the FES-gait training intervention. His

BBS score improved to 42 out of 56, and he could stand unsupported with feet together for 1 minute with eyes open or 10 seconds with eyes closed with supervision. He could walk independently using a cane and had a gait speed of 0.35 m/s. He still required physical support for climbing up stairs and for walking up a steep slope (FAC scale level 4). His independence in ADL improved, as shown by his BI score of 75.

Patient B

At the end of the 4-week intervention, patient B could walk independently and required only verbal encouragement or supervision by one physical therapist (FAC scale level 3). His walking speed had improved to 0.31 m/s (Tab. 1). Patient B was independent in all transfers and maintained balance in standing without support with feet together. His BBS score increased from 16 to 42. Motor function showed improvement, especially in his knee extension and ankle dorsiflexion control and the muscle strength on the paretic side. His total Motricity Index leg score increased from 38 to 48. Observational gait analysis showed improvements in foot clearance and trunk control. Moreover, flexion in the hip increased in the swing phase, and therefore a larger step length was observed for both sides during walking. He was partially independent in self-care as well as in ambulation, and his BI score was 60.

In a follow-up assessment 6 months after the end of the FES-gait training intervention and discharge from the

hospital, patient B could walk independently with the help of a cane, including climbing up stairs, and had a FAC scale level of 5. He had received outpatient postdischarge stroke rehabilitation for 2 months and acupuncture treatment twice a week for 2 months after being discharged. Clonus reflex was still present, but the frequency was lower. He was independent in most ADL tasks, except in some activities such as tying shoelaces and fastening fasteners (BI score=90).

Discussion

In our gait training program, 2 patients with motor deficits secondary to stroke demonstrated improved

Table 5.
Patient B: Daily Record of Intervention Sessions

Day	Body Weight Support (%)	Gait Speed (m/s)	No. of Rest Breaks	Total Distance Walked (m)	Total Session Time (min)
1	13.0	0.17	0	108	10
2	9.2	0.20	0	243	17
3	7.3	0.22	0	288	19
4	3.7	0.22	1	225	15
5	3.7	0.25	0	259	16
6	3.7	0.25	0	310	18
7	1.8	0.25	0	320	19
8	1.8	0.25	0	347	20
9	1.8	0.25	0	380	20
10	1.8	0.25	0	250	16
11 ^a					
12	3.7	0.28	1	260	15
13	1.8	0.25	1	270	18
14	1.8	0.25	1	310	20
15	1.8	0.28	0	380	20
16	3.7	0.28	2	380	20
17	3.7	0.28	1	320	20
18 ^a					
19	1.8	0.28	0	315	17
20	1.8	0.31	0	374	20

^a No data because of a missed training session due to a conflicting scheduled phenal block injection appointment and a clinical psychologist appointment.

ambulation and balance during and after gait training on an electromechanical gait trainer coupled with simultaneous FES. These outcomes are consistent with those of previous studies that evaluated gait training on a gait trainer alone in patients following stroke,¹³⁻¹⁶ as well as a study that investigated gait training on a gait trainer with simultaneous FES in patients following spinal cord injury.³³

Before being admitted into our gait training program, patient A and patient B had already undergone 2 and 3 weeks of the hospital's conventional rehabilitation program, respectively, but they did not display much improvement in their walking and motor abilities. During our 4-week FES-gait training intervention, both patients received an additional repetitive activity of 500 to 800 steps per session via the gait trainer with simultaneous FES. As they went through more sessions, they showed improvements in balance and gait. Both patients made progress mostly on the BBS and in overground walking speed. In their 6-month follow-up assessments, patient A showed less improvement than patient B, but both patients had a faster walking speed and displayed better functional performance than at the end of the 4-week FES-gait training intervention and discharge from the hospital. Their independence in ADL also improved compared with that before the intervention.

Although the gait trainer helped with movement of the legs and feet during the stance and swing phases as well as assisting in weight shifting and control of the center of mass, the gait trainer was unable to provide knee control

during weight bearing or ankle dorsiflexion during the terminal swing of the paretic lower limb.¹⁵ With the help of synchronized FES, the knee extensors and ankle dorsiflexors were used to generate more capacity for weight bearing on the affected side. During gait training, we found that the stance phase was supported effectively by FES-induced muscle activations and without continuous manual support by a physical therapist. The patients also reported they were willing to put more weight on their paretic lower limb because they felt that the FES-induced contraction brought additional strength to their leg during the single-leg stance phase. In addition, the tingling sensation of FES served as a cue for when to extend their knee and to dorsiflex their ankle during the gait cycle, which may have helped them to actively try to walk during the gait training, compared with perhaps passively reacting to the repetitions of electrical stimulation of their paretic muscles during their conventional rehabilitation program.

We used FES to promote muscle strength, lower-limb circulation, and bone mineralization.³⁴ The novelty and value of using a gait trainer together with FES was to enable gait practice for more than 500 steps in a walking-like movement with corresponding muscle contraction. Patients who were nonambulatory could train in a highly symmetric gait pattern without the need for an enormous amount of physical help from a therapist, which in turn we believe increased their confidence and provided more exercise in the gait training. Patient B also may have gained a cardiopulmonary training effect after the intervention because the total number of rest

breaks that he requested in the latter sessions was smaller than during the initial sessions, and his endurance had increased so that he was able to complete the last 20-minute gait training session without a rest.

The basic training process and progression definition that we followed in our gait training program were those set by the designers of the gait trainer, and we made adjustments to the training gait speed, electrical stimulation parameters, amount of hand support, and percentage of BWS. In our gait training program, the percentage of BWS and the FES intensity could be reduced based on the patient's progress in the training session. For example, patient B did not demonstrate adequate knee control, so we reduced the percentage of BWS in the first 7 sessions of the 4-week intervention. We then increased the amplitude of the stimulation current to his quadriceps femoris muscle on his affected side on day 8 to achieve better knee extension and to help his weight bearing during the stance phase of the paretic lower limb. Patient B performed better and was able to complete the 20-minute sessions after day 8.

The outcomes of our gait training program demonstrate that it may be practical to integrate FES into electromechanical gait training without adverse effects. However, further randomized controlled studies are needed to evaluate whether the patient outcomes of combined training are superior to those of electromechanical gait trainer treatment alone or conventional gait training alone.

This case report presented the details of a new gait training intervention that combines the use of a gait trainer with simultaneous FES, and this may be useful information for possible implementation of the combined method within a clinical setting. As such, the emphasis of this case presentation was to lay out details of the application of this new intervention combination in rehabilitation training for patients who are nonambulatory in the early stage after stroke within a hospital setting.

Conclusion

After the end of the 4-week FES-gait training intervention, the 2 patients showed improvements in their functional activities, balance, motor control, ambulation ability, and gait pattern. This case report showed that FES-gait trainer intervention is feasible for use in rehabilitation. That is, the 2 independent modalities of using a gait trainer and FES can be coupled for gait training with no prohibitive adverse effects encountered based on the positive outcomes from the 2 patients during the acute post-stroke stage as well as 6 months after the end of the FES-gait trainer intervention. In addition, both patients were satisfied with the combination of modalities.

Further randomized controlled group studies would be invaluable to determine the efficacy of comparing FES-gait trainer intervention with conventional treatment alone or usage of a gait trainer alone in gait rehabilitation after stroke.

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