CASE REPORT

Effects of Prosthetic Gait Training for Stroke Patients to Induce Use of the Paretic Leg: A Report of Three Cases

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Abstract. During recovery from a stroke, body weight-bearing on a paretic leg is spontaneously avoided. In physiotherapy for hemiparetic gait, as long as the patients can use their non-paretic leg, adaptive and compensatory strategies are always used to support and move the body. We examined the effects of gait training using prosthetics to induce the use of a paretic leg during walking. The prosthesis was applied to the non-paretic leg of three right hemiparetic patients. Prosthetic gait training was performed until finishing 5 successive motor learning sessions involving walking over 200 m and the changes of asymmetric gait performances were analyzed. The ground reaction forces during the initial stance phase of the paretic leg were increased in all patients after prosthetic gait training. Simultaneously, the propulsive force produced by the paretic leg was increased in 2 patients. By contrast, another patient developed more use of his non-paretic leg for propulsion corresponding to acquiring stability on the paretic leg, resulting in an improvement in single-support-time asymmetry. Task-specific effects provided by prosthetic gait training may be able to reorganize the motor strategy for hemiparetic gait by inducing the use of the paretic leg to support and propel the body. (Keio J Med 57 (3) : 162 –167, September 2008)

Key words: Case report, Stroke, Prosthetics, Rehabilitation, Gait training

Introduction

The common movement pattern in hemiparetic patients is based on an asymmetric motor strategy to compensate for functional deficits of a unilateral body. In view of motor learning theory, physiotherapeutic efficacy for hemiparetic gait has been obtained from reproducing a gait performance by assisting impaired functions with various devices and repeating it under appropriate training sessions to lead to output-optimization. A recent development of gait assisting devices such as a body weight-supported treadmill system[1] and gait training methods such as a task-oriented training program[2,3] improves the functional achievements of hemiparetic gait. However, as long as hemiparetic patients can use their non-paretic leg, adaptive and compensatory strategies are always used to support and move the body.[4,5] While performing pre-ambulation exercises to improve paretic leg function,[6] such as kicking a ball against a wall[2] or jumping from a standing position,[7] gait training *per se* that provides a task-specific effect by inducing the paretic leg to support and propel the body should be included in the series of task-oriented training.

Functional cortical reorganization depends on how much the paretic limb will be used to perform the required task. Moreover, clinical and neurophysiological studies have suggested that the reduced sensory input from the non-paretic limb will provide functional improvements of the paretic limb.[8] Because the postural control to maintain the standing posture are mainly based on the sensory information from below the knee,[9] removal of afferent inputs from below the knee of the non-paretic leg may facilitate motor learning in gait performance. Amputees require compensatory motor strategies by the sound leg to control their standing posture with a prosthesis[10] similar to hemiparetic postural control based

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Table 1. Patient characteristics and training schedules

	Patient characteristics						Training schedules
Patients	Age	Sex	Stroke (type/lesion)	Duration (months)	SIAS-m (L/E)	MAS of ankle (ankle clonus)	Total number of sessions*
1	42 y	male	CI/MCA	7	4-4-3	1 (4-5 beats)	12 (7)
2	60 y	female	CH/thalamus	78	4-4-4	1 (2-3 beats)	14 (9)
3	56 y	male	CI/ACA	43	4-3-2	1 (sustained)	16 (11)

CI; cerebral infarction, CH; cerebral hemorrhage
ACA; anterior cerebral artery, MCA; middle cerebral artery
SIAS-m (L/E); stroke impairment assessment set-motor of lower extremities [6] is shown in order of hip (hip flexion test), knee (knee extension test), and ankle (foot pat test) joint.
MAS: modified Ashworth scale [1] of ankle plantar flexors
*; Note that the number of sessions for adaptation training is indicated in the parenthesis.

on non-use of the paretic leg.[11] Therefore, by applying a prosthesis to the non-paretic leg, we may be able to induce use of the paretic leg in hemiparetic gait. In order to realize a forced-use of the paretic leg together with reduced input from the non-paretic leg, we applied a prosthesis to the non-paretic leg in hemiparetic gait training. In this first clinical trial of prosthetic gait training for 3 hemiparetic patients, raw data of ground reaction force pattern during gait will be shown to reveal a process of the motor learning.

Case Description

To prevent a secondary injury of the paretic leg in the first clinical study on prosthetic gait training, hemiparetic patients who could independently ambulate with a prosthesis even if they underwent amputation of the non-paretic leg[12] were enrolled to this study. The inclusion criteria were as follows; (1) no significant perceptual and communication disturbances; (2) independently walking without a cane and orthosis; (3) no pain in the low back and legs; (4) no severe proprioceptive dysfunction. The degrees of motor score and muscular tonus of the paretic leg were evaluated by the Stroke Impairment Assessment Set (SIAS)[13] and modified Ashworth scale (MAS),[14] respectively. The baseline characteristics of the three enrolled right hemiparetic patients are given in Table 1. Before participating in the study, the patients gave their informed consent to the gait training program using a prosthesis and gait analysis schedules described below.

The prosthesis designed to simulate an amputee's gait was used for hemiparetic gait training (Figure 1). Since muscular overactivity of the non-paretic leg during walking may prevent functional improvements of the paretic limb,[8] the prosthesis was designed to give stability during a period of prosthetic stance. The socket holding the non-paretic leg in the flexed knee position was prescribed to individual patients. The knee and ankle joints
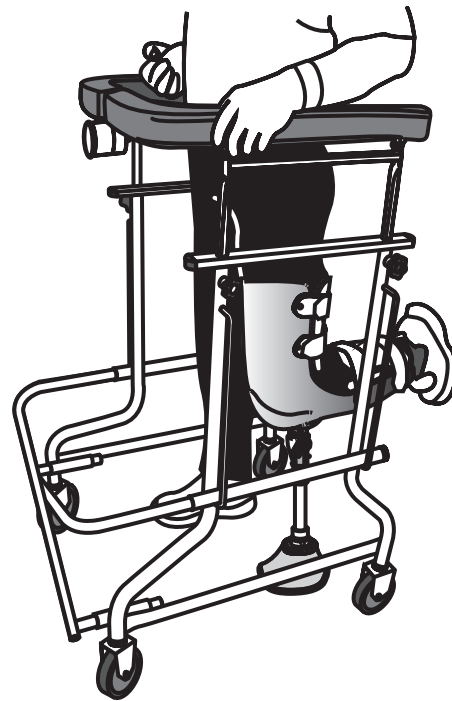

Fig. 1 A prosthesis applied to the non-paretic leg of a right hemiparetic patient.
  The weight of the prosthesis including a socket and custom foot device is about 2.5 kg in total. To force use of paretic lower limb in the propulsive (push-off) phase of gait, the forefoot portion of the custom foot device is cut about 5 cm shorter, and a rocker bottom is provided to facilitate toe-clear during the early swing phase of gait.

were fixed at 0° and a custom foot device was made up of a flat and wide sole, with a rocker bottom to allow easier toe-clear. As a result, hemiparetic patients using the prosthesis and a walker with 4 casters would be able to perform rhythmic gait training by dominantly using the paretic leg.
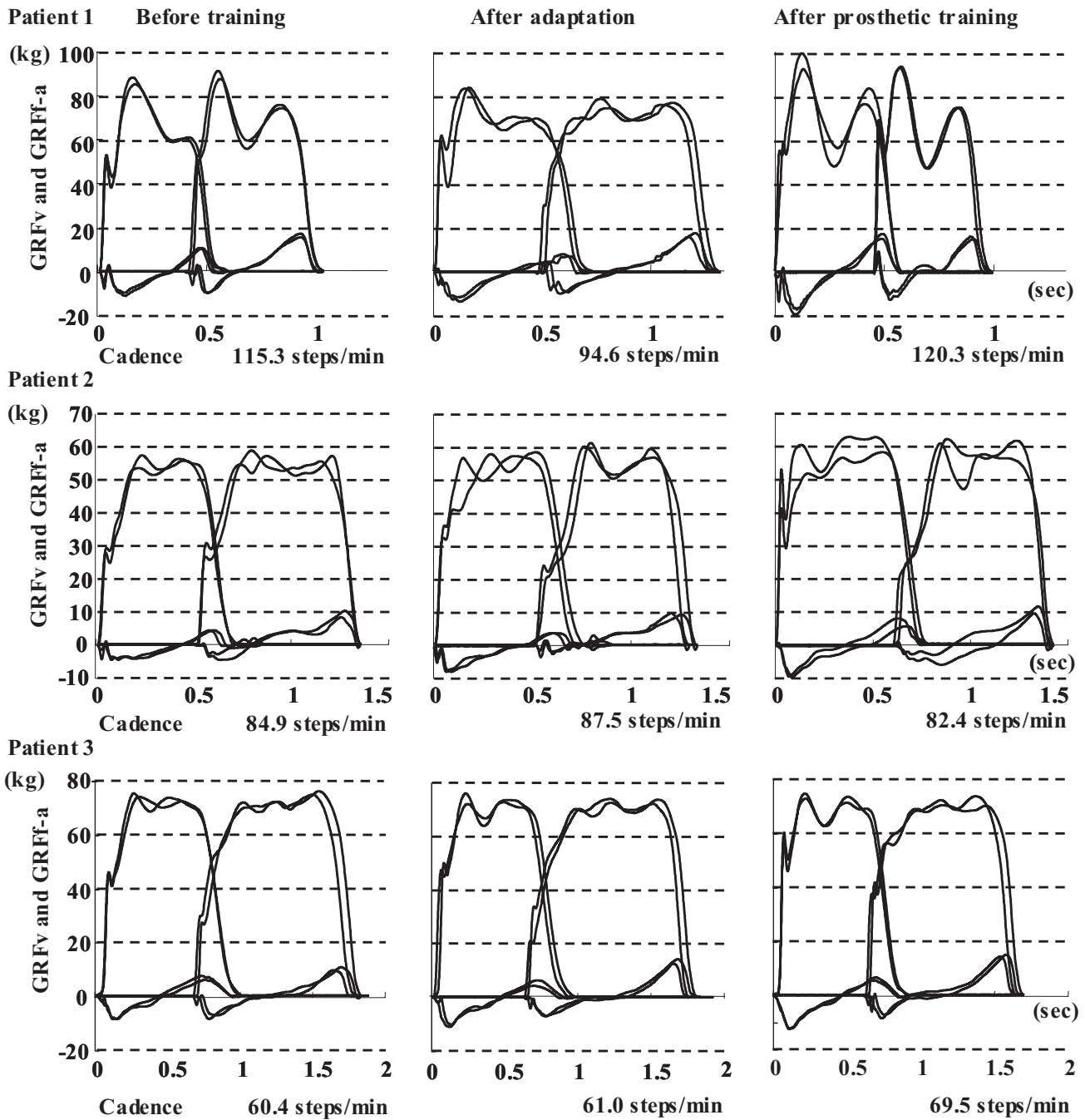
Fig. 2 Force plate data before and after prosthetic gait training
  Raw data on the vertical and fore-aft components of the ground reaction forces (GRFv and GRFf-a) from three subjects before and after prosthetic gait training. Two representative gait cycles beginning with force traces under the paretic foot are shown.

Prosthetic gait training was carried out 2 to 3 times per week over 5 weeks. In the early training sessions, the prosthetic gait was so strenuous for them that the patients were asked only to walk with as symmetrical stance durations as possible and keep the trunk upright during gait. For safety, the physiotherapist supported the pelvis.

The training was stopped when patients were physically exhausted or hyperextension of the paretic knee joint occurred during the stance phase. After patients were comfortably able to walk over 200 m in 5 successive training sessions, the physiotherapist encouraged and facilitated extension of the paretic limb hip joint during the late

Table 2.   Asymmetry and walking velocity before and after prosthetic gait training

a) Kinetic asymmetry

Patients	Braking force			Propulsive force		
	Pre-training	Post-adaptation	Post-training	Pre-training	Post-adaptation	Post-training
1	1.36	1.33	3.21	0.46	0.49	1.24
2	2.41	6.69	3.33	0.36	0.37	0.46
3	0.84	1.20	3.15	1.09	0.72	0.31

b) Kinematic asymmetry

Patients	Single-support-time			Step-length		
	Pre-training	Post-adaptation	Post-training	Pre-training	Post-adaptation	Post-training
1	0.80	0.75	0.79	0.99	1.05	1.04
2	0.78	0.84	0.90	1.05	1.21	1.18
3	0.63	0.86	1.01	0.96	1.08	1.00

Note; all of asymmetry ratio are indicated by (paretic data/non-paretic data)

c) Maximum walking velocity   (m/sec)

Patients	Pre-training	Post-adaptation	Post-training
1	1.61	1.59	2.03
2	1.33	1.34	1.54
3	1.15	1.22	1.32

stance phase. After each training, gentle muscular stretching of the paretic lower limbs was performed, watching for muscular pain and tonus. The total training time required was only 15 to 20 minutes including stretching exercises.

Using force platforms (Model MG-1090, Anima Co., Tokyo), vertical and fore-aft components of the ground reaction forces, GRFv and GRFf-a, respectively, were measured over 5 gait cycles during walking without shoes and any devices at a comfortable speed. Under the same conditions, spatial and temporal gait patterns were analyzed by a 6 m instrumented pathway (GAITRite; CIR Systems, Inc., NJ). Also the fastest comfortable speed while walking across a 10 m walkway was measured.

Gait analyses were planned before the training, after 5 successive prosthetic training sessions of over 200 m (called adaptation training), and after 5 subsequent training sessions with physiotherapeutic motor learning. Post-training evaluations were performed at intervals of more than 48 hours between each session to estimate the prolonged effects on gait performance.

The GRFf-a traces were divided into the braking and propulsion phases by the baseline. Each trajectory was integrated to obtain a total braking and propulsive force respectively, and the ratio between the forces generated by the paretic and non-paretic leg was calculated to quantify the force asymmetry. Additionally, step-length and single-support-time asymmetry were calculated as a simple ratio of paretic leg to non-paretic leg from the instrumented pathway analyses data.

The motor score and muscular tonus of the paretic leg were unchanged after training. Figure 2 shows the data of GRFv and GRFf-a together with cadence for each patient before and after prosthetic gait training. Each figure contains two representative data sets of different gait cycles. After the training, transient peaks of the GRFv increased in all patients just after heelstrike and backward components of the GRFf-a during the initial period of the paretic stance phase.

Patient 1, who had finished an intensive treadmill gait exercise for 2 weeks before participating in the study, needed time for a gait cycle after the initial series of prosthetic gait training. But the successive 5 training sessions with physiotherapeutic motor learning organized a rhythmic gait pattern with increased paretic propulsive forces. The GRFf-a data for patient 2 also showed larger paretic propulsive forces with increased non-paretic braking forces after prosthetic gait training. These resulted in increased step length of the non-paretic leg (data not shown). In contrast, paretic propulsive forces in patient 3 decreased slightly. Simultaneously, the non-paretic propulsive forces increased by a factor of about 1.5.

Table 2 shows the mean values of the kinetic and kinematic asymmetry ratios as well as the maximum walking velocity for each patient. The asymmetry ratio values over 1.00 mean a greater measure for the paretic than the non-paretic leg. The prosthetic gait training increased braking forces of the paretic leg in all patients. However, the changes in the asymmetry ratio of the propulsive force differed from patient to patient. The post-training paretic propulsive force in patient 1 somewhat increased

compared with the non-paretic leg. In patient 2, the asymmetry ratio of the propulsive force also gradually increased, but it remained under 0.5. Most interestingly, the propulsive force ratio in patient 3 became more assymetrical with increases of the non-paretic propulsive force. As to kinematic asymmetry, the single-support-time asymmetry in patient 3 improved and the step length in patient 2 increased somewhat in the paretic leg. Consequently, the fastest walking speed markedly increased in all three patients.

Discussion

Task-specific training can induce functionally relevant adaptive changes in the human brain after focal injury.[15] When a stroke patient can reproduce motor performance to develop the skill, rehabilitative treatments to maximize functional motor recovery of the paretic limb must be applied. Such effective therapeutic strategies leading to cerebral reorganization have developed through increasing somatosensory inputs from the paretic limb and reducing ones from the non-paretic limb,[8] such as constraint-induced movement therapy for the upper limb.[16] However, difficulty exists in constraining the movement of the non-paretic leg during bipedal walking and usual gait training *per se* may produce an asymmetrical gait pattern based on compensatory motor strategies.[17] Indeed, accelerated gait pattern ability which patient 1 relearned through the treadmill gait training before participating in this study depended on the reduced weight-bearing on the paretic leg in the push-off phase (Figure 2).

The most common characteristics of hemiparetic gait are decreased ankle and hip powers to propel the body.[18,19] We hoped that the paretic propulsive force would be reorganized after prosthetic gait training. This actually developed in patients 1 and 2, coupled with increased paretic braking force. In contrast, patient 3, who appears to have difficulty in developing ankle plantarflexor moment due to severer palsy (Table 1), started to use his non-paretic leg increasingly to produce propulsive force. As a result, his kinetic asymmetry increased, whereas the temporal asymmetry improved. Indeed, for all of the patients, the adaptation to walk with a prosthesis began with stabilizing the paretic leg against the impact from the floor around the heelstrike. It could be induced by a task-specific effect, to which unavailable compensatory support of the trailing non-paretic leg with a prosthesis in the double support phase contributed. Lamontagne *et al*[4,20] reported that the motor strategy in non-paretic leg during hemiparetic gait was characterized by a reduced stance phase plantarflexor moment combined with excessive antagonistic coactivation at ankle and suggested that it may result from an adaptation for poor postural stability during gait. Through the pros-

thetic gait training, which reduces compensatory movements by the non-paretic knee and ankle joint and sensory inputs from the non-paretic leg, the relearned ability to control the body weight on the paretic leg thus should allow the non-paretic leg to generate propulsive force by the active push-off movement.[20]

On the other hand, while adapting to walking with a prosthesis, there is a potential risk that patients may learn a gait pattern based on paretic knee hyperextension during stance phase, which could hinder a smooth forward shifting of the body-weight on the paretic leg and predispose to joint or ligamentous injury. In case of forming dynamic knee instability during the prosthetic gait training, the preparatory exercises to obtain the ability to stabilize the paretic knee in closed kinetic chain such as a tracking training[21,22] may be required. Also the normal joint proprioception would be very important in preventing knee hyperextension movements and in learning an appropriate gait pattern.

Patients who cannot dynamically manage a body-mass including prosthesis on the paretic leg should be excluded from this training. Because we can control the ankle motion by using an ankle-foot orthosis, the clinical indications of the prosthetic gait training depend on proximal motor functions of the paretic leg, that are, the abilities to voluntarily move a hip and knee joints against gravity. However, recent advances in an assist-based hemiparetic gait training such as a body weight-supported system enable stroke patients with a severe palsy to walk rhythmically. The potential application of prosthetics to the assist-based trainings may extend the clinical indications of the prosthetic gait training and cause additional effects to the assist-based hemiparetic gait trainings that mainly reorganize the rhythmical gait pattern by facilitating improvements of the abilities of the paretic leg to support the body and control equilibrium during gait.

Even if 1 year passes from the prosthetic gait training intervention, the 3 patients appear to keep their ability to stabilize the body on the paretic leg in the early stance phase without any trouble of the musculoskeletal system. They explained the extended effects of the prosthetic gait training such as increased stability when standing in moving train or getting into the tub. The long-term effect including occurrence of a secondary injury must be evaluated in future study. Also, there is need of clinical trials to compare with other methods of gait training and to verify the effect on the patient with various severities of symptoms.

In conclusion, this report provides evidence indicating that the gait training using a prosthesis may reorganize the motor strategy for hemiparetic gait by inducing the use of the paretic leg to support and propel the body. It has to contain the process of physiotherapeutic motor learning to optimize the gait pattern. The task-specific effects provided by prosthetic gait trainings may make it

possible for stroke patients to dramatically develop their gait abilities.

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