Clinical Rehabilitation 2005; **19:** 264–273

Gait outcomes after additional backward walking training in patients with stroke: a randomized controlled trial

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Received 23rd July 2004; returned for revisions 9th September 2004; revised manuscript accepted 13th October 2004.

Objective: To examine the effectiveness of additional backward walking training on gait outcome of patients post stroke.
Design: Randomized controlled trial.
Setting: Medical centre.
Subjects: Twenty-five subjects with stroke, who were lower extremity Brunnstrom motor recovery stage at 3 or 4 and were able to walk 11 m with or without a walking aid or orthosis, randomly allocated to two groups, control ($n = 12$) and experimental ($n = 13$).
Interventions: Subjects in both groups participated in 40 min of conventional training programme three times a week for three weeks. Subjects in experimental group received additional 30 min of backward walking training for three weeks at a frequency of three times per week.
Main measures: Gait was measured using the Stride Analyzer. Gait parameters of interest were walking speed, cadence, stride length, gait cycle and symmetry index. Measures were made at baseline before commencement of training (pre-training) and at the end of the three-week training period (post-training).
Results: After a three-week training period, subjects in experimental group showed more improvement than those in control group for walking speed (change score: 8.60 ± 6.95 versus 3.65 ± 2.92, p-value $= 0.032$), stride length (change score: 0.090 ± 0.076 versus -0.0064 ± 0.078, p-value $= 0.006$), and symmetry index (change score: 44.07 ± 53.29 versus 5.30 ± 13.91, p-value $= 0.018$).
Conclusions: This study demonstrated that asymmetric gait pattern in patients post stroke could be improved from receiving additional backward walking therapy.

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10.1191/0269215505cr860oa

Introduction

Since loss of walking ability is a major problem after stroke,[1,2] recovery of walking is a priority goal for most patients.[3,4] Friedman showed that the sooner the individual with a history of stroke attained the ability to ambulate, the more likely it was that independent walking would be re-established.[2] Gait outcome is a significant factor that influences a patient's chance of returning to their premorbid environments.[2] Rehabilitation can be an effective treatment following stroke,[5] however some patients may be dissatisfied with the level of function they achieve.[1,6]

The gait of the person with hemiplegia has been described as slow and asymmetric.[7–9] The diminished velocity of the hemiplegic gait, in comparison to normal, has been reported repeatedly along with associated limitation in cadence, stride length and gait cycle.[10,11] The velocity decrement has potentially important functional implications. For example, many environmental factors, such as signals at pedestrian crossings, are geared towards a much faster walking velocity.[12] This slow walking velocity has traditionally been attributed to decreased joint movement amplitudes and step lengths as well as an inability to produce selective movement in the joints of the lower limb and poor balance.[13,14] Attempts to increase walking velocity by hemiplegic subjects may result in problems of safety and a more abnormal gait pattern. This deterioration of performance appears to be worthy of consideration as an important rehabilitation concern.

Asymmetry is also a characteristic of post-stroke gait. The typical hemiplegic gait is characterized by asymmetry of timing in single-limb support phase on the affected and unaffected legs.[8,15,16] The asymmetrical gait pattern leads to increased energy expenditure and risk of falls.[17–19] Consequently improvements in symmetry provide an important clinical marker of recovery. Conventional gait training alone often leads to an asymmetrical gait pattern in many patients with stroke.[20,21]

Learning to walk backwards correctly has been recommended to improve the movement components required for walking forwards.[22] Backward walking, therefore, has been promoted as a treatment strategy to improve gait. During backward walking the same motor programme is used as during forward walking, but possibly running in reverse.[23,24] It has been suggested that backward walking may offer some benefits beyond those experienced through forward walking alone. Backward walking appears to create more muscle activity in proportion to effort than forward walking.[24,25] This suggests a greater level of energy expenditure in backward walking than in forward walking.[24] Additionally, backward walking also demands a greater oxygen consumption, metabolic response and cardiorespiratory than forward walking.[26,27]

Backward walking combines hip extension with knee flexion and is particularly useful for patients with hemiplegia with synergy influence in the lower extremities.[28] While backward walking training is currently being used by some therapists, there are no published data to document the effectiveness of backward walking training for patients with hemiparesis. The purpose of the present study was to examine the effectiveness of additional backward walking training on gait outcome of patients post stroke with lower extremity Brunnstrom motor recovery stage at 3 or 4.

Methods

Subjects

The subjects participating in this study were recruited by convenience sampling from the rehabilitation outpatient department of a medical centre in Taipei, Taiwan. The diagnosis, age, sex, affected side and onset time of hemiparesis were obtained from patient interviews and medical charts. The stage of motor recovery of the lower extremities was determined by Brunnstrom recovery stage.[14] The inclusion criteria were (1) first cerebrovascular accident; (2) unilateral motor and/or sensory deficit; (3) lower extremity Brunnstrom motor recovery stage at 3 or 4; (4) ability to walk 11 m with or without a walking aid or orthosis; (5) stable medical condition to allow participation with testing protocol and intervention; and (6) ability to understand instructions and follow commands. The exclusion criteria were (1) patient with any comorbidity or disability other than stroke that would preclude gait training; (2) any uncontrolled health condition for which exercise is contraindicated; and (3) orthopaedic and other gait-influencing diseases.

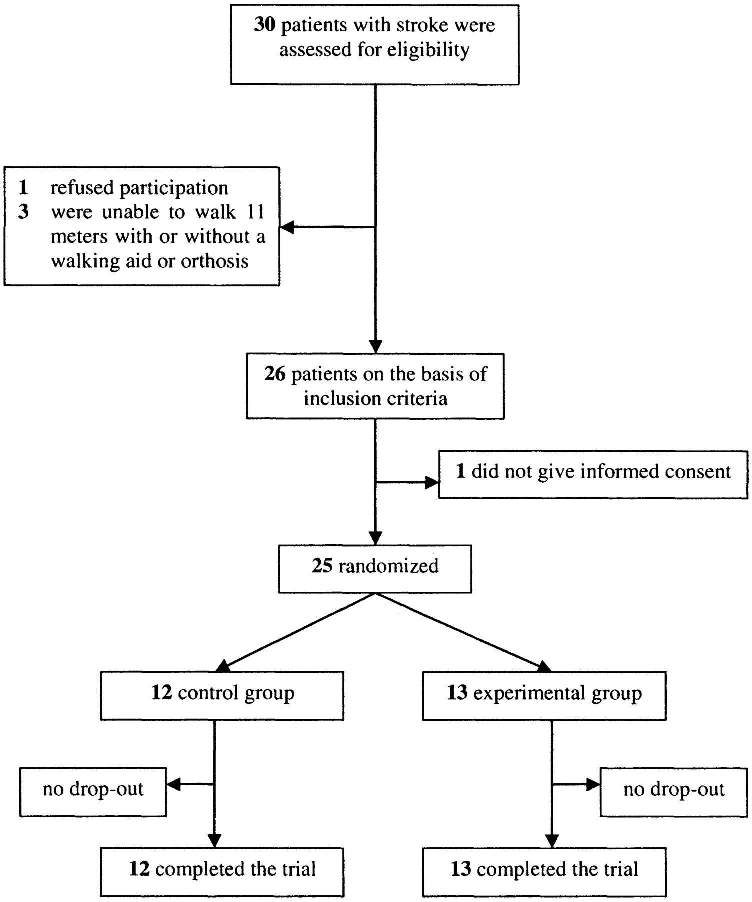

Figure 1 Flow diagram of the study.

Procedure

The study protocol was reviewed and approved by the Human Subject Review Boards of Cheng Hsin Rehabilitation Medical Center of Republic of China. Prior to data collection, the purposes and procedures were fully explained, and informed consents were obtained from the patients. Thirty subjects were identified as potential participants for this study. Four were excluded because they failed to meet the inclusion criteria (Figure 1). Twenty-five subjects signed an informed consent before participating in the study. Participants were randomized to the control group or experimental group by an independent person who picked one of the sealed envelopes 30 min before the start of the intervention. All subjects were evaluated before commencement of training (pre-training) and at the end of the three-week training period (post-training). The 12 subjects in the control group received the conventional stroke rehabilitation programme. They did not receive any additional training. The remaining 13 subjects in the experimental group received the conventional programme plus backward walking training.

Intervention

Subjects in both groups participated in 40 min of conventional training programme three times a week for three weeks. The conventional training programme focused on strengthening, function and mobility activities, including gait training. The gait preparatory training section takes up approximately 20–30% of each session's time.

All conventional training sessions were performed by a qualified and experienced physical therapist. Subjects in the experimental group received additional 30 min of backward walking training for three weeks at a frequency of three times per week.

The backward walking training programme was based on methods as described by Davies.[22] First, the subject is asked to take a step backwards within parallel bars and can support him- or herself with the unaffected hand as required. The therapist provides assistance to move the subject's leg in the correct pattern; preventing the subject from moving the leg back in full extension. When the subject can move the leg back with the correct pattern, the therapist gradually reduces the amount of assistance. Secondly, as the movement components have been practised, and the subject has taken over actively with only slight help, the therapist facilitates walking backwards within parallel bars. Thirdly, the subject walks backwards actively away from the parallel bars. Finally, the distance and speed of walking backwards is progressively increased. All backward walking training sessions were performed by qualified and experienced physical therapist.

Measurement

The temporal and distance parameters of gait were measured by the Stride Analyzer (B/L Engineering, USA). The system consists of a pair of innersoles with compression-closing footswitches, which are responsive to weight-bearing, positioned at the great toe, first metatarsal, fifth metatarsal and the heel. The innersoles come in a variety of sizes, and the forefoot and heel portions can be overlapped to accommodate differing shoe sizes. During a measured walk the footswitch data are stored in a backpack, which is worn at the waist. Following data acquisition, data were transferred from the recorder unit to a personal computer for display, storage, and analysis.

A smooth, flat 11-m walkway was marked out on the floor in the physical therapy department. Markers were placed at the 1- and 10-m points along the walkway, thus defining the central 9 m for data collection. A handheld trigger, activated by a researcher walking behind the subject, was used with the Stride Analyzer to initiate data collection as either foot crossed the 1-m mark and to complete data collection as either foot crossed the 10-m mark of the walkway. In this way data were collected over the middle 9 m of the 11-m walkway, thus avoiding the acceleration and deceleration phases of gait.

The handheld trigger was selected for data collection because speed measures obtained by a handheld device correlate closely with those obtained from light-sensitive automatic triggers.[29]

The testing protocol used standardized instructions. The test–retest reliability coefficient for gait outcomes in a subset of stroke survivors in our lab ranged from 0.89 to 0.98. The assessor was not blinded to the group of the patients. However, all data were automatically stored on a computer and were not assessed until all patients had completed the trial.

All subjects were requested to walk at a self-selected, comfortable walking speed. Two trials were undertaken. For safety reasons there was standby supervision throughout the process although no physical assistance was provided. There was a 5-min rest period between each trial. The subjects remained seated between trials and the innersoles were not removed. The average of two trials was used for data analysis.

When gait outcomes were measured, the innersoles were adjusted to fit precisely and symmetrically into each shoe, and the footswitches were checked with the testing unit. Leads from the innersoles were attached to the data recorder. The subjects took a short walk of several meters to become familiar with the innersoles in the shoes. The subjects were allowed to use walking aids such as walking canes or foot-ankle orthoses. For better comparability, the same walking aids were used during each measurement.

The temporal–spatial parameters recorded were: velocity (m/min), cadence (steps/min), stride length (m), gait cycle (s), affected single-limb support (% of gait cycle), and unaffected single-limb support (% of gait cycle). The temporal symmetry index was calculated using the formula: $2 \times$ [(affected single-limb support $-$ unaffected single-limb support)/(affected single-limb support $+$ unaffected single-limb support)] $\times 100$.[30,31] Acceptable symmetry was considered an temporal symmetry index of $< 10\%$.[30]

Data analysis

Information from all subjects were entered into a computerized database and analysed using the SPSS statistical package. Descriptive statistics were calculated for the clinical characteristics of each group. To compare the baseline demographic characteristics and the pre-training gait variables between groups, independent-samples *t*-tests were used for means and chi-square tests were used for frequencies. To elucidate the effect of training, the differences on all gait variables between the pre- and post-training phases within group were analysed by paired *t*-tests. Difference scores were calculated for each patient by subtracting the pre-training data from the post-training data. Mean difference scores, and the standard deviation of these changes scores were calculated for each variable. Multivariate analysis of variance (MANOVA) was used to determine differences of mean difference scores of each gait variable between groups. A significance level of 0.05 was set for all analyses.

Results

Of the 25 subjects, 12 were randomly allocated to the control group, and the other 13 subjects were randomly allocated to the experimental group. Table 1 indicates the group means and standard deviations for age and stroke onset and the frequency counts for gender, hemiparetic side and Brunnstrom stage of lower extremity. There were no statistically significant differences between groups for age, stroke onset, gender, hemiparetic side, and Brunnstrom stage of lower extremity. Table 1 also outlines the pre-training data on the gait parameters of subjects randomized into the control and experimental groups. These pre-training data were also found to be similar (mean ± standard deviation) between groups, respectively.

As shown in Table 2, the gait parameters of the patients only partially improved after conventional training alone. The gait velocity and cadence increased significantly, a 13.8% improvement ($p = 0.001$) and a 14.6% improvement ($p = 0.001$), respectively. Gait cycle decreased significantly, a 10.5% reduction ($p = 0.013$). However, improved stride length and symmetry index were not demonstrated. Following additional backward walking training, significant improvement was found in all gait parameters (Table 2). The gait velocity had a 34.7% improvement ($p = 0.001$). Cadence had a 20.4% improvement ($p = 0.006$). Stride length had a 12.5% improvement ($p = 0.002$). Gait cycle had a 20% reduction ($p = 0.005$). Symmetry index had a 74.6% improvement ($p = 0.015$).

Table 1 Baseline demographic and gait variables for control and experimental groups

	Control group ($n = 12$)	Experimental group ($n = 13$)	*p*-value
Demographic variables			
Age (years)[a]	63.42 ± 11.06	63.38 ± 7.7	0.99
Months post stroke[a]	7.33 ± 2.42	5.45 ± 3.03	0.10
Gender			
Male	9 (75%)	10 (76.9%)	0.91
Female	3 (25%)	3 (23.1%)	
Hemiplegic side			
Right	8 (66.7%)	8 (61.5%)	0.79
Left	4 (33.3%)	5 (38.5%)	
Brunnstrom stage of lower extremity			
Stage 3	5 (41.7%)	5 (38.5%)	0.87
Stage 4	7 (58.3%)	8 (61.5%)	
Gait variables			
Velocity (m/min)[a]	25.97 ± 14.86	24.83 ± 6.69	0.80
Cadence (steps/min)[a]	67.69 ± 17.47	62.42 ± 9.45	0.35
Stride length (m)[a]	0.70 ± 0.23	0.78 ± 0.12	0.25
Gait cycle (s)[a]	1.93 ± 0.46	1.96 ± 0.29	0.83
Symmetry index[a]	− 37.84 ± 36.82	− 59.06 ± 26.66	0.12

[a] Mean ± standard deviation.

Table 2 Gait measurements for control and experimental groups

Variable	Scores						Change scores		
	Control ($n = 12$)			Experimental ($n = 13$)			Control ($n = 12$)	Experimental ($n = 13$)	
	Pretest	Posttest	p-value[a]	Pretest	Posttest	p-value[a]	Posttest–pretest	Posttest–pretest	p-value[b]
Velocity (m/min)	25.97 ± 14.86	29.62 ± 16.35	0.001	24.83 ± 6.69	33.43 ± 5.20	0.001	3.65 ± 2.92	8.60 ± 6.95	0.032
Cadence (steps/min)	67.69 ± 17.47	77.58 ± 18.01	0.001	62.42 ± 9.45	75.07 ± 8.22	0.006	9.90 ± 7.49	12.65 ± 13.57	0.54
Stride length (m)	0.70 ± 0.23	0.69 ± 0.25	0.78	0.78 ± 0.12	0.88 ± 0.096	0.002	−0.0064 ± 0.078	0.090 ± 0.076	0.006
Gait cycle (s)	1.93 ± 0.46	1.67 ± 0.40	0.013	1.96 ± 0.29	1.62 ± 0.18	0.005	−0.26 ± 0.31	−0.35 ± 0.37	0.55
Symmetry index	−37.84 ± 36.82	−32.55 ± 39.90	0.20	−59.06 ± 26.66	−14.99 ± 58.55	0.015	5.30 ± 13.91	44.07 ± 53.29	0.018

Data were expressed as mean ± standard deviation.

[a] Within-group comparison.

[b] Between-group comparison.

The mean difference scores of the pre-training and post-training scores for velocity, cadence, stride length, gait cycle and symmetry index were compared for the control and experimental groups with the use of MANOVA. The analysis revealed significant differences between the two groups for three of five variables, as illustrated in Table 2. There were significant differences between the control and experimental groups for velocity ($p = 0.032$), stride length ($p = 0.006$) and symmetry index ($p = 0.018$). However, no significant differences were found for cadence ($p = 0.54$) and gait cycle ($p = 0.55$).

Discussion

It has been cited, but unproven, that the indications for backward walking therapy include difficulty with weight shift, balance and gait in patients with hemiparesis and hemiparesis with a strong lower limb synergy pattern.[28] The results of this randomized trial suggest that additional backward walking training may help improve walking abilities in individuals with hemiparetic stroke. In addition to the significant improvement of patients in the experimental group, the authors observed a good acceptance of the backward walking training, although this is not a goal of the study.

Asymmetry was one of the most obvious features of the abnormal gait of patients with stroke. The mean temporal symmetry index for single-limb support phase was significantly high ($> 10\%$), indicating that marked asymmetries are present. The majority of patients showed an asymmetrical gait pattern with less time spent on the affected leg during single-limb support than on the unaffected leg. One of the specific goals in gait training is the restoration of gait symmetry, in order to regain a physiological gait pattern. However, Hesse *et al*. found that there was no significant improvement in gait symmetry parameters after an intensive four weeks inpatient rehabilitation programme based on the neurodevelopmental technique.[32] Although treadmill induces an immediate alteration toward a more consistent and symmetric gait pattern,[33,34] three months of graded treadmill exercise produced no significant improvement in gait symmetry.[35] The present study demonstrated that patients with hemiparesis can benefit in having their gait symmetry improved from receiving additional backward walking therapy. This is more effective than just conventional training alone. Therefore, it could be suggested that backward walking training may be an appropriate training modality to add to the conventional programme for improving patients' asymmetric gait pattern.

In contrast to normal subjects the hemiplegic gait pattern is characterized by low values for velocity, cadence and stride length and high value for gait cycle duration.[15] Many sources note that improvements in walking speed are strongly correlated with improvements in walking ability in patients with hemiparesis.[36,37] The results of this study concur with this viewpoint. In addition to speed gains, it has been observed that cadence, stride length, gait cycle and gait symmetry were significantly improved in the experimental group, and that cadence and gait cycle were greatly improved in the control group (Table 2). Moreover, for patients with reduced walking ability, increasing walking speed results in giving that patient a greater behavioural repertoire in everyday life.[38] Changes in walking speed as low as 6 m/min are probably the smallest clinically worthwhile effect worth detecting.[39] In the present study, the mean difference for walking speed in the experimental group was 8.6 m/min. This is a small but clinically relevant gain in this patient group. In the control group, the mean difference for walking speed was below 6 m/min.

It has been suggested that velocity showed a strong potential for differentiating the three groups of community walkers (most, least and unlimited).[40] In our study, the initial gait speeds of 26.0 ± 14.9 m/min for the control group and 24.8 ± 6.7 m/min for the experimental group suggested that functional walking ability of our patients was between most-limited and least-limited community walkers as defined by Perry *et al*.[40] The experimental group achieved a mean gait speed (33.43 m/min), just under the threshold for least-limited community walkers (35 m/min) following a three-week intervention, whereas no marked improvement in functional walking ability was obtained in the control group. More recently, Lord *et al*. suggested that gait speed might be a measure that discriminates between different categories of community ambulation.[41] However, of itself, it is not sufficient as a single measure of community ambulation and should be augmented by self-report and the use of measures of social integration and community participation.[41]

The present study showed significant improvement of the experimental group compared with the control group in the area of walking velocity, stride length and gait symmetry (Table 2). In patients with hemiparesis, the extensor synergy predominates in the lower extremity. Hip extension with knee flexion was emphasized by Bobath to break up the synergy pattern.[7] The isolated movements of the knee alternating flexion with extension were repeatedly practised in the backward walking training and may contribute to improve neuromotor control for patients with hemiparesis with synergy influence in the lower extremities. Moreover, Winter *et al*. concluded that backward walking was a near mirror image of forward walking.[25] They reported that in order to produce the muscle activation patterns involved in forward walking the temporal cycling of the muscle contractions in backward walking is simply reversed.[25] This is also a possible reason for the improved gait performance after additional backward walking training.

There are several limitations of this study. First, the number of subjects in this trial was limited, which means that care should be exercised in the interpretation of the results. However, this may somewhat be compensated by the homogeneity of the groups. Second, due to limited resources this study did not use a blinded assessor. Any potential for unblinding to bias the study results was minimized by the use of standard instructions during testing. Third, we did not have a control for the additional therapy. The participants in the control group did not receive any 'placebo' intervention. It has been suggested that intensive rehabilitation programmes are often of great benefit.[42] The significant improvement on walking speed was also observed following treadmill training or task-related circuit training in similar groups of patients.[43,44] Therefore, additional forward walking therapy or other approaches might also help. Future studies should control these potential sources of bias.

Clinical messages

- Adding a backward walking programme to a conventional training programme can result in a significant improved walking speed, stride length and gait symmetry in individuals with hemiparetic stroke compared with conventional training alone.
- Additional backward walking training may be an appropriate training modality to add to the conventional programme for improving patients' asymmetric gait pattern.

This study demonstrates that backward walking plus conventional training is an effective and safe approach. It can result in superior walking ability in ambulatory hemiparetic patients comparing with running mere conventional rehabilitation programmes without backward walking. Thomas and Fast presented two cases in which walking backwards during physical therapy resulted in a fall and considerable morbidity.[45] They therefore doubted the safety of walking backwards. In this study, none of our subjects fell down during backward walking training. Backward walking requires a greater reliance on neuromuscular control, proprioception and protective reflexes because of the elimination of visual cues. It is important that adequate safeguards should be provided when backward walking is prescribed.

Acknowledgements

This study was supported partly by the Cheng Hsin Rehabilitation Medical Center and partly by the National Health Research Institutes of the Republic of China (grant no. NHRI-EX92-9129EI).

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