

Effect of forced use of the lower extremity on gait performance and mobility of post-acute stroke patients

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Abstract. [Purpose] The purpose of this study was to investigate the effects of a forced-use training program on gait, mobility and quality of life of post-acute stroke patients. [Subjects] Twenty-one individuals with unilateral stroke participated in this study. All participants had suffered from first-ever stroke with time since onset of at least 3 months. [Methods] A single-blinded, non-equivalent, pre-post controlled design with 1-month follow-up was adopted. Participants received either a forced-use or a conventional physical therapy program for 2 weeks. The main outcomes assessed were preferred and fastest walking velocities, spatial and temporal symmetry indexes of gait, the timed up and go test, the Rivermead Mobility Index, and the Stroke-Specific Quality of Life Scale (Taiwan version). [Results] Forced-use training induced greater improvements in gait and mobility than conventional physical therapy. In addition, compared to pre-training, patients in the conventional physical therapy group walked faster but more asymmetrically after training. However, neither program effectively improved in-hospital quality of life. [Conclusion] The forced-use approach can be successfully applied to the lower extremities of stroke patients to improve mobility, walking speeds and symmetry of gait.

Key words: Stroke, Forced-use, Mobility

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INTRODUCTION

Stroke is an epidemic worldwide. It is the second leading cause of death in the world¹⁾, and the third leading cause of death in Taiwan²⁾. More importantly, it is a leading cause of long-term disability in adults³⁻⁵⁾. It has been recognized that individuals with stroke-related hemiparesis bear most of the body weight on their unaffected limb despite the fact that the affected limb may already be able to bear weight efficiently during the course of recovery⁶⁻⁹⁾. Weight-bearing asymmetry in stance and during functional activities may arise from compensatory patterns learned in the early post-stroke period known as learned misuse or disuse after stroke¹⁰⁻¹³⁾. If the disuse is left uncorrected, it may lead to further balance impairments, gait abnormalities and ambulation dysfunction^{8, 10, 13)}. Forced-use training (FUT) is a

treatment strategy, designed to compel usage of the more-affected limb by intensive practice of task-oriented activities to shape behavior, and was originally developed for upper extremity rehabilitation following stroke¹¹⁾. Controlled experiments have shown that constraint-induced movement therapy (CIMT), a version of forced-use training, is effective at overcoming the learned non-use of affected upper limbs and elicits significant improvements in motor function and real-life usage of the affected upper limb after cerebrovascular accidents^{14, 15)}. Studies have also shown that CIMT or modified CIMT (CIMT with less training intensity) can improve some aspects of quality of life (QOL) in chronic or elderly stroke survivors^{16, 17)}. Therefore, it would appear sensible to conduct CIMT, or FUT for individuals with stroke to enhance the recovery of the affected lower extremity and independence in functional mobility. Efforts have been made to force the use of the affected lower limb of stroke patients by rehabilitation professionals. Essentially, placing joints of the affected leg into biomechanically disadvantaged positions¹⁸⁾, or simply immobilizing the joints by splinting^{19, 20)}, have been used to restrain the unaffected lower limbs of stroke patients. Single limb exercise²¹⁾ or unilateral step training²²⁾ have also been used to work the affected lower limb intensively. Furthermore, intensive, practice of gait-

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related activities without restraint of the unaffected limb has improved the gait performance of individuals with multiple sclerosis to a certain degree²³). However, owing to the bipedal nature of human locomotion and mobility, forced-use by constraint of the unaffected limb or intensive unilateral use of the affected limb may actually prevent walking or functional mobility performance or practice in task-oriented ways.

It has been shown that shoe inserts (shoe lift or shoe wedge) fitted under the unaffected lower extremity of stroke patients forces the affected limb to bear more weight and resume a more symmetrical weight-bearing stance^{8, 24, 25}). When a shoe insert (7-degree wedge) was fitted to a group of stroke patients and worn during physical therapy sessions for three weeks, it significantly improved gait speed²⁶). It is important to note that shoe inserts not only compel the stroke patients to shift the body weight onto the paretic leg but also permit functional mobility to be performed in natural ways. Since task-oriented training for mobility enhances gait performance and mobility after stroke²⁷), we hypothesized that combined with the use of a weight-shift insert, it would help to overcome learned disuse of the affected lower extremity of stroke patients. Therefore, the purpose of this study was to investigate the effects of a forced-use training program which utilized a weight-shift technique and task-oriented lower extremity training on gait performance, mobility and QOL of sub-acute or chronic stroke patients.

SUBJECTS AND METHODS

The subjects were a convenience sample from the inpatient rehabilitation unit of the Tao-Yuan Branch of Chang Gung Memorial Hospital in northern Taiwan. Inclusion criteria were stroke patients suffering from their first-ever stroke, three months or longer post-stroke, with a Brunnstrom stage of the affected lower extremity between III to V, a Mini-Mental State Examination score ≥ 24 , a Functional Ambulation Category score ≥ 2 , and the ability to walk 3 meters with or without an assistive device, who attended of physical therapy sessions five times a week for 2 weeks. Subjects were excluded if they had any medical condition that would have restricted their participation in the exercise program, such as congestive heart failure, or uncontrolled hypertension. Pre-existing neurological conditions other than stroke or musculoskeletal conditions that would have confounded the training effects also served as exclusion criteria. All subjects signed informed consent documents before data collection, and all procedures were performed in accordance with the approval granted by the Institutional Review Board for Human Subject Research of Chang Gung Memorial Hospital (92-504).

An assessor-blind, non-equivalent pretest-posttest control group design with 1 month follow-up was adopted as the design scheme. To avoid diffusion of the treatment effects, forced-use training (FUT) or conventional physical therapy (CPT) was offered in two separate periods of the year in the same rehabilitation ward. In order to equalize the training intensity of the groups, both groups received 90 minutes training per day, 5 times a week, for 2 weeks. The CPT program provided gait correction, treadmill training, postural

training and other training activities prescribed by physical therapists to improve functional mobility. Participants in the FUT group wore a custom-fitted wedged insole under the unaffected side to force the use of the affected limb during all floor activities during the two-week period and during a daily, circuit training program. The wedged insole of the unaffected shoe was made of multi-layered cork to provide 5 degrees of elevation on the lateral border of the unaffected foot. The circuit training program was designed to work the affected lower extremity in a functionally relevant way^{8, 28}). Specifically, it included 5 workstations: sit-to-stand, stepping over blocks in different directions, walking on an inclined treadmill, climbing stairs, and walking over various surfaces with obstacles. All training activities in the FUT group were conducted by the same physical therapist who constantly adjusted the difficulty of each task according to patients' abilities and encouraged maximal usage of the affected limb while performing those tasks.

Performance of gait and mobility were assessed by the preferred and fastest walking velocities (PWV; FWV), spatial and temporal symmetry indexes (SSI; TSI), the timed up and go (TUG) test, and the Rivermead Mobility Index (RMI), while the quality of life was assessed using the Stroke-Specific Quality of Life Scale Taiwan Version (SSQOLTV). Walking velocity was measured and gait parameters were derived using an electronic walkway system (GAITrite, CIR system Inc., USA). The equations used to compute symmetry of gait have been described elsewhere^{29, 30}) and they were adopted by this study as follows:

- Spatial symmetry index (SSI) =

$$\frac{(\text{US Step length} - \text{AS Step length})}{0.5 \times (\text{US Step length} + \text{AS Step length})} \times 100\%$$

- Temporal symmetry index (TSI) =

$$\frac{(\text{US Stance time} - \text{AS Stance time})}{0.5 \times (\text{US Stance time} + \text{AS Stance time})}$$

US: Unaffected side; AS: Affected side

The subjects were assessed three times, before the training (pre-training), at the end of the training (post-training), and 1 month later (follow-up) by a licensed physical therapist who was independent of the study.

The between-group comparisons of demographic data and pretest scores were analyzed using the independent t-test, Mann-Whitney U test, or χ^2 test. Changes in values from pre-training to post-training, and from post-training to follow-up were calculated for walking velocities, TUG times and SSQOLTV scores and were analyzed by mixed two-way ANOVA (2X2) with repeated measures. Analysis of simple main effects by one-way ANOVA or one-way ANOVA with repeated measure was performed if interaction effects were detected. Owing to the bi-directional nature of the symmetry index, SSI and TSI were analyzed as their original scores by mixed two-way ANOVA (2X3) with repeated measures, while the Friedman with Wilcoxon test and Mann-Whitney

U test were used to compare within or between-groups differences of RMI scores. All of the statistical analyses were conducted using the Statistical Package for Social Sciences version 11.0 for Windows (SPSS Inc., USA).

RESULTS

Twenty-one individuals with stroke were enrolled in this study. There were no significant differences between the FUT and CPT groups in baseline characteristics or mobility variables, except that the SSQOLTV score was higher in the FUT group than in the CPT group at pre-training (Table 1).

Forced-use training produced greater improvement than CPT in mobility and most gait parameters (PWV, $p < 0.001$; FWV, $p < 0.01$; RMI: $p < 0.05$; TUG: $p < 0.05$) (Table 2). In addition, the improvements of both groups were either larger at follow-up than immediately after training (PWV, $p < 0.001$; FWV, $p < 0.05$) or remained the same across time (TUG: $p = 0.98$). Only FUT elicited an improvement in RMI from pre- to post-training ($p < 0.05$), and from pre-training to follow-up ($p < 0.05$) (Table 2). While patients in the FUT group walked more symmetrically (SSI at FWV moved toward 0: pre-training to follow-up, $p < 0.05$), patients in the CPT group walked more asymmetrically after training (SSI at PWV moved away from 0: pre training to follow-up, $p < 0.05$). There were no significant differences in the changes of quality of life and TSI between the two groups (SSQOLTV: $p = 0.57$; TSI at PWV: $p = 0.68$; TSI at FWV: $p = 0.28$) and over the whole observation period (SSQOLTV: $p = 0.62$; TSI at PWV: $p = 0.15$; TSI at FWV: $p = 0.86$).

DISCUSSION

The results of this study confirm that FUT for the affected lower extremity improved stroke patients' walking velocity and mobility more than conventional physical training with the same training intensity. In addition, while patients in the FUT group walked with a more symmetrical gait pattern, patients in CPT walked more asymmetrically at follow-up. However, the superior training effects of FUT on walking performance and mobility did not lead to better in-hospital quality of life. Walking velocity has been considered a preferred outcome measure of functional ambulation ability

Table 1. Demographic and characteristics of the participants (n=21)

	CPT (n=10)	FUT (n=11)
Gender ^a	M: 6, F: 4	M: 5, F: 6
Age (yrs)	54.2 (11.1)	56.8 (11.0)
Weight (kg)	61.8 (11.1)	69.6 (8.9)
Height (cm)	162.1 (9.2)	160.4 (7.8)
Time post-stroke (yr)	1.0 (0.5)	1.2 (1.3)
Brunnstrom stage (III / IV / V) ^b	2 / 5 / 3	3 / 6 / 2
Ischemic stroke ^a	8/10	5/11
R't hemi ^a	5/10	4/11
FAC ^c	4 (0.8)	4 (0.8)

Values are shown as the mean (SD). $p < 0.05$: ^a, χ^2 test; ^b, Fisher Exact Test; ^c, Mann-Whitney U test.

CPT: Conventional physical training group, FUT: Forced-use training group, R't hemi: Hemiparetic on right side, M: Male, F: Female, FAC: Functional ambulatory category

Table 2. Mobility measures and SSQOLTV score (n=21)

Outcome	Scores						Gains			
	CPT (n=10)			FUT (n=11)			CPT (n=10)		FUT (n=11)	
	Pre	Post	Follow-up	Pre	Post	Follow-up	Post-Pre	Follow-Pre	Post-Pre	Follow-Pre
Velocity (m/s)										
Preferred	44.1 (23.4)	47.6 (22.0)	60.1 (29.8)	39.5 (15.5)	70.7 (23.2)	81.9 (28.5)	3.5 (5.7)	16.0 (13.6) ^a	31.2 (11.4) ^b	42.3 (17.0) ^{ab}
Fast	64.8 (32.3)	69.8 (38.0)	74.5 (38.4)	67.7 (26.3)	92.6 (31.4)	97.2 (34.2)	5.0 (15.6)	9.7 (17.6) ^a	24.9 (12.6) ^b	29.3 (14.7) ^{ab}
TUG (s)	21.9 (13.3)	19.9 (10.4)	19.7 (12.7)	22.2 (10.5)	16.1 (6.7)	16.3 (7.1)	2.0 (4.0)	2.2 (6.5)	6.2 (4.6) ^b	5.9 (4.1) ^b
SSQOLTV	162.8 (29.5)	175.9 (18.9)	184.6 (29.3)	193.3 (25.0) ^c	206.2 (20.6)	201.5 (19.2)	13.1 (39.5)	21.8 (41.4)	12.8 (8.0)	8.1 (13.9)
SSI										
Preferred	1.9 (27.9)	-18.7 (28.8)	-14.0 (37.4) ^d	-20.2 (36.2)	-4.4 (11.5)	-2.1 (18.7)				
Fast	-1.6 (40.6)	-19.2 (28.5)	-20.0 (33.2)	-14.8 (24.1)	-4.3 (9.2)	-0.6 (14.8) ^d				
TSI										
Preferred	15.4 (7.4)	19.5 (11.0)	15.3 (13.2)	16.7 (11.5)	15.4 (7.2)	13.0 (10.4)				
Fast	17.2 (14.6)	20.0 (10.1)	19.4 (10.3)	14.8 (12.6)	14.4 (9.4)	13.9 (8.0)				
RMI	12.4 (1.9)	12.8 (1.4)	13.2 (1.5)	12.9 (2.6)	14.2 (1.2) ^{e f}	14.6 (0.9) ^{e f}				

Values are expressed as mean (SD).

Significant differences, $p < 0.05$: ^a, Paired t-test (within group effect); ^b, Independent t-test (between group effect); ^c, Independent t-test (between group effect of pre-training); ^d, Paired t-test (within group effect on pre-training to follow-up); ^e, Post-hoc Wilcoxon test after Friedman test (within group effect on pre-training to post-training and follow-up); ^f, Kruskal-Wallis test (between group effect on post-training and follow-up).

CPT: Conventional physical training group; FUT: Forced-use training group; TUG: Timed up and go test; SSQOLTV: Stroke specific quality of life, Taiwan version; SSI: Spatial symmetry index; TSI: Temporal symmetry index; RMI: Rivermead mobility index

due to its simplicity and reliability of its measurement, and more importantly, its predictive ability for independence of community ambulation^{31,32}). In the present study, forced-use training elicited 9 times greater improvement than conventional physical therapy in mean preferred walking velocity (gain of 31.2 cm/s vs. 3.5 cm/s) and 5 times greater improvement in fast walking velocity (gain of 24.9 cm/s vs. 5.0 cm/s) immediately after training and both walking velocities continued to improve through to follow-up (preferred walking, 81.9 cm/s; fast walking, 97.2 cm/s). In view of the fact that the mean preferred walking speed attained by the FUT group at follow-up exceeded the speed required for community ambulation (80 cm/s), and thus promotes upgrading of ambulation classification; the FUT program used in the present study could be considered to promote successful walking recovery in stroke patients³¹). The beneficial effects of this forced-use training program were also confirmed by measures of basic as well as functional mobility skills (TUG and RMI). Essentially, improvements or values of TUG and RMI in the FUT group were consistently larger than those of the CPT group at post-training and follow-up, and only the FUT group showed significant changes in RMI scores after training. Improvements in the gait performances and mobility observed after FUT may be explained by the successful combination of a forced compelled weight-bearing approach and a relatively intensive task-oriented mobility training. Using a shoe wedge or shoe lift for the unaffected foot facilitates symmetrical weight bearing by stroke patients during quiet stance, and thus may help to overcome the learned disuse of the affected lower extremity of stroke patients⁸). Alternatively, Kim and Eng proposed that increased weight bearing by the paretic limb may increase feedback from load receptors to the central nervous system, thereby improving gait symmetry³³). Though, the present study did not measure the symmetry of weight bearing achieved by the 5-degree shoe wedge, patients in the FUT group did show more symmetrical gait after fitting of the wedge. When a shoe wedge was combined with weight bearing feedback and 30 minutes of gait training for 15 sessions²⁶), or shoe lift was combined with goal-directed balance training⁷), improvements in gait speed, dynamic balance, and gait symmetry of stroke patients were also recognized. However, the walking velocities achieved by the above-mentioned methods^{7,26}) (0.35 m/s to 0.54 m/s) never reached the speed required to walk independently in the community³¹). Since intensive mobility training and treadmill training combined with task-specific practice have been found to improve gait ability effectively³⁴), we believe that the task-oriented circuit training focused on improving mobility used in this study contributed in part to the pronounced effect on gait speed observed in this study. However, effects of the training programs on QOL were not realized in the present setting. It is possible that in an in-hospital setting, the environment may pose less of challenge on the quality of life than that in the real life³⁵), and the gains in gait performance and mobility may not exert their full impact on QOL. In addition, the SSQOLTV score of the FUT group was relatively high, approaching the ceiling of the scale (193.3/245) at pre-training, which may have limited the room for training-related improvement. The limitations of this study include its small sample size, the unmatched

quality of life between the two groups at pre-training, our inability to randomly assign patients to the two treatment groups, and the short follow-up period which measured quality of life in the hospital rather than in a real life situation. A randomized control trial with multiple follow-ups is warranted to verify the effectiveness of FUT for stroke patients at different phases of recovery. In conclusion, two-weeks of ninety minutes per day, 5 days per week forced-use training improved walking velocities and functional mobility more effectively than conventional physical therapy at a similar training intensity. Five degrees of shoe wedge under the unaffected foot combined with intensive, task-oriented gait and mobility training should be an optimal strategy for forced-use training for the affected lower extremity of stroke patients in the sub-acute or chronic stage.

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