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ORIGINAL ARTICLE

Robotic Resistance/Assistance Training Improves Locomotor Function in Individuals Poststroke: A Randomized Controlled Study

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Abstract

Objective: To determine whether providing a controlled resistance versus assistance to the paretic leg at the ankle during treadmill training will improve walking function in individuals poststroke.

Design: Repeated assessment of the same patients with parallel design and randomized controlled study between 2 groups.

Setting: Research units of rehabilitation hospitals.

Participants: Patients (N=30) with chronic stroke.

Intervention: Subjects were stratified based on self-selected walking speed and were randomly assigned to the resistance or assistance training group. For the resistance group, a controlled resistance load was applied to the paretic leg at the ankle to resist leg swing during treadmill walking. For the assistance group, a load that assists swing was applied.

Main Outcome Measures: Primary outcome measures were walking speed and 6-minute walking distance. Secondary measures included clinical assessments of balance, muscle tone, and quality of life. Outcome measures were evaluated before and after 6 weeks of training and at 8 weeks' follow-up, and compared within group and between the 2 groups.

Results: After 6 weeks of robotic training, walking speed significantly increased for both groups, with no significant differences in walking speed gains observed between the 2 groups. In addition, 6-minute walking distance and balance significantly improved for the assistance group but not for the resistance group.

Conclusions: Applying a controlled resistance or an assistance load to the paretic leg during treadmill training may induce improvements in walking speed in individuals poststroke. Resistance training was not superior to assistance training in improving locomotor function in individuals poststroke.

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Walking dysfunction is one of the physical limitations contributing to stroke-related disability.[1] Most stroke survivors walk with reduced walking speed[2] and endurance,[3] as well as with residual spatial and temporal asymmetry.[4] Walking dysfunction reduces the probability of successfully returning to work and decreases participation in community activities.[5] As a consequence, improved walking function is a major goal of rehabilitation in individuals poststroke.

The use of body weight supported treadmill training (BWSTT) has demonstrated significant improvements in walking capability in individuals poststroke. For instance, previous studies have indicated significant improvements in gait velocity,[6-9] endurance,[10] balance,[7] and symmetry[11] after BWSTT. However, BWSTT can be labor-intensive work for physical therapists, particularly when working with patients who require substantial walking assistance after stroke.[6]

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Several robotic systems have been developed for automating locomotor training.[12,13] These robotic systems are effective in reducing therapist labor and increasing the total duration of training. However, their use has shown relatively limited functional gains for some patients[14-16] because of the limitations of these robotic systems. For instance, the limited degrees of freedom of current robotic systems allows movement only in the sagittal plane, which may limit the natural walking pattern and affect gait dynamics.[17] In addition, the fixed trajectory control strategy used in current robotic systems may encourage passive rather than active training.

Active motor training has been demonstrated to be more effective than passive training in eliciting performance improvement.[18] In particular, data from hemiparetic subjects practicing upper limb movements with forces that provide passive guidance versus error enhancement indicate that greater improvements in performance are achieved when errors are magnified,[19] suggesting that error-augmentation training may also be used as an effective way to improve locomotor function in individuals poststroke. Thus, we postulated that by applying a controlled resistance load to increase kinematic errors (ie, the difference between the predicted leg movement outcomes and the observed outcomes of the leg movement) of the paretic leg during treadmill walking, motor learning would be accelerated during BWSTT in individuals poststroke.

On the other hand, providing a controlled assistance load to the paretic leg may facilitate leg swing, which mimics the way that therapists provide assistance to the paretic leg during treadmill training. We postulated that providing an assistance load to the paretic leg may also improve locomotor function in individuals poststroke through a use-dependent motor learning mechanism.[20] To date, no randomized controlled studies have directly compared leg resistance versus assistance during BWSTT in individuals poststroke. The purpose of this study was to assess locomotor function (ie, walking speed, endurance, balance) after resistance versus assistance training in individuals poststroke. We hypothesized that subjects from both groups would show improvements in locomotor function, although there would be greater improvements in subjects who underwent resistance training in comparison with those who underwent assistance training. Results from this study may be used to develop robotic training paradigms to improve locomotor function in individuals poststroke.

Methods

Participants

Screening evaluations were performed on 82 subjects, and 30 individuals with chronic hemiparetic stroke were recruited to participate in this study (tables 1 and 2). Inclusion criteria included (1) unilateral, supratentorial, ischemic, or hemorrhage stroke; (2) >6 months' duration after stroke; (3) no prior stroke; (4) self-selected walking speed ≤.99m/s; and (5) able to stand and walk (>10m) without physical assistance using assistive devices or orthoses (below knee) as needed. Exclusion criteria included (1) significant cardiorespiratory/metabolic disease and (2) score <24 on the Mini-Mental State Examination.[21] All subjects required medical clearance for participation. All procedures were approved by the institutional review board. Written informed consent was obtained from all subjects.

Of the 30 participants enrolled in the study, 2 dropped out. The remaining 28 participants completed all training and test sessions. There were no significant differences in the training parameters between the resistance and assistance training groups, except for the peak forces applied (table 3).

List of abbreviations:

ABC	**Activities-specific Balance Confidence**
ANOVA	**analysis of variance**
BBS	**Berg Balance Scale**
BWSTT	**body weight−supported treadmill training**
F/U	**follow-up**

Table 1 Characteristics of participants

Characteristics	Resistance	Assistance	*P*
Age (y)	53.6±8.9	57.4±9.8	.30
Sex (M/F)	9/5	9/5	.99
Race (white/other)	4/10	6/8	.16
Side of paresis (R/L)	7/7	7/7	.99
Type of stroke (ischemic/hemorrhagic)	6/6*	6/6*	.99
Time postinjury (y)	7.3±5.6	7.1±6.0	.95
Ankle-foot orthosis	7	7	.99
Assistive device	7	9	.34

NOTE. Values are mean ± SD, n, or as otherwise indicated.
Abbreviations: F, female; L, left; M, male; R, right.
* One subject reported unknown cause of stroke and 1 reported aneurysm in resistance training group; 2 subjects reported unknown cause of stroke in assistance training group.

Apparatus

A custom-designed, cable-driven robotic gait training system, which has been reported previously,[22] was used to provide a controlled resistance or assistance load to the paretic leg during treadmill walking (fig 1). One of the cables was attached to the

Table 2 Subjects screened, enrolled, and tested

Screening Status	Number of Subjects
Screened	80
Excluded	52
	Multiple stroke (n=12)
	Brainstem lesion (n=2)
	Other diagnoses (such as brain injury or spinal cord injury) (n=7)
	Walking too quickly (ie, self-selected walking speed >1.0m/s) (n=11)
	Needed physical assistance to ambulate (n=5)
	Did not meet MMSE criteria (n=1)
	Not interested because of travel or time constraints (n=14)
Included	30
	Completed all training and test sessions (n=28)
Dropped out (n=2)	
Poor attendance (n=1)	
Feeling "decreased balance" (n=1)	

Abbreviation: MMSE, Mini-Mental State Examination.