

High-Intensity Resistance Training Improves Muscle Strength, Self-Reported Function, and Disability in Long-Term Stroke Survivors

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Background and Purpose—To evaluate the efficacy of supervised high-intensity progressive resistance training (PRT) on lower extremity strength, function, and disability in older, long-term stroke survivors.

Methods—Forty-two volunteers aged 50 years and above, 6 months to 6 years after a single mild to moderate stroke, were randomized into either a control group of upper extremity stretching or a PRT group that received a 12-week supervised high-intensity resistance training program consisting of bilateral leg press (LP), unilateral paretic and nonparetic knee extension (KE), ankle dorsiflexion (DF), and plantarflexion (PF) exercises. Functional performance was assessed using the 6-minute walk, stair-climb time, repeated chair-rise time, and habitual and maximal gait velocities. Self-reported changes in function and disability were evaluated using the Late Life Function and Disability Instrument (LLFDI).

Results—Single-repetition maximum strength significantly improved in the PRT group for LP (16.2%), paretic KE (31.4%), and nonparetic KE (38.2%) with no change in the control group. Paretic ankle DF (66.7% versus –24.0%), paretic ankle PF (35.5% versus –20.3%), and nonparetic ankle PF (14.7% versus –13.8%) significantly improved in the PRT group compared with the control. The PRT group showed significant improvement in self-reported function and disability with no change in the control. There was no significant difference between groups for any performance-based measure of function.

Conclusions—High-intensity PRT improves both paretic and nonparetic lower extremity strength after stroke, and results in reductions in functional limitations and disability. (*Stroke*. 2004;35:1404-1409.)

Key Words: exercise ■ cerebrovascular accident ■ rehabilitation ■ recovery of function

Approximately 15% to 30% of stroke survivors are permanently disabled, making stroke a leading cause of serious long-term disability in the United States.¹ A major impairment causing disability in these patients is motor weakness.^{2,3} In some patients, the resultant hemiparesis adversely affects functional mobility, including gait quality^{4–6} and sit-to-stand ability.^{7,8} Muscle weakness, as reflected by bilateral knee extensor strength, is a significant predictor of walking ability in individuals 1 year poststroke.⁹

Progressive resistance exercise has been used successfully to restore function in older adults with chronic disease and frailty.¹⁰ Yet, insufficient evidence exists regarding the efficacy of strength training on function and disability in chronic stroke survivors. Some studies have evaluated the effects of lower extremity strength training on changes in gait and functional performance measures in individuals following stroke. However, these studies have used a relatively low training intensity,¹¹ used small sample sizes,^{12,13} were non-

randomized,^{12,14} and used strength training in combination with other treatment strategies,^{11,13,14} or a combination thereof.

To date, no study has evaluated the efficacy of high-intensity lower extremity PRT alone on function and disability in chronic stroke survivors. The purpose of this study was to conduct a controlled, single-blinded intervention trial of lower extremity PRT and to compare this intervention to a placebo control intervention in older long-term stroke survivors and to (1) compare changes in lower extremity strength and power, and (2) assess whether lower extremity strength gains after PRT improve function and reduce disability.

Methods

Subjects

Subjects were recruited through local newspaper advertisements and through referrals from a local volunteer database and stroke support network. Inclusion criteria included subjects aged ≥ 50 years, 6 months to 6 years following a single unilateral mild to moderate

Received October 23, 2003; final revision received December 16, 2003; accepted January 8, 2004.

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Stroke is available at <http://www.strokeaha.org>

DOI: 10.1161/01.STR.0000127785.73065.34

stroke (via Orpington Prognostic Scale^{15,16}) with residual lower extremity hemiparesis, community dwelling, independent ambulation with or without an assistive device, report of 2 or more limitations on the physical function subscale (PF 10) of the Medical Outcomes Survey Short-Form,¹⁷ ability to travel to the exercise laboratory, and willingness to be randomized. Stroke was diagnosed by history and clinical examination, and confirmed via medical records review. Eligible subjects completed a medical history questionnaire and underwent a physical examination and a submaximal graded exercise test. Exclusion criteria included myocardial infarction within the past 6 months, symptomatic coronary artery disease or congestive heart failure, uncontrolled hypertension (>150/90 mm Hg), fracture within the past 6 months, acute or terminal illness, score ≤ 20 on the Mini-Mental State examination,¹⁸ inability to follow a 3-step command, current participation in regular strength training or supervised physical therapy, or pain during exercise. All intervention sessions were supervised by trained staff. Subjects provided written informed consent and were randomized after baseline assessments were completed. All study procedures were in accordance with institutional guidelines and were approved by the Institutional Review Board.

PRT Intervention

Subjects performed seated bilateral leg press (LP), unilateral paretic and nonparetic limb knee extension (KE), unilateral ankle dorsiflexion (DF), and plantarflexion (PF) 3 times per week for 12 weeks. The LP and KE were performed using pneumatic resistance training equipment (Keiser Sports Health Equipment Inc) and the PF and DF were performed using a modified weight stack-pulley system (Therapy Systems). Four warm-up repetitions at 25% of the 1-repetition maximum (1RM) were performed followed by 3 sets (8 to 10 repetitions per set) at 70% of the 1RM. Training intensity was adjusted biweekly by reassessing the 1RM.

Control Intervention

The control intervention consisted of bilateral range of motion (ROM) and upper body flexibility exercises performed 3 times per week.

Muscle Strength and Peak Power

Lower extremity muscle strength was quantitatively assessed by 1RM measures (LP and KE).¹⁹ The reliability of repeated 1RM testing of LP and KE in our sample was determined to be excellent with intraclass correlation coefficients (ICCs) ranging from 0.82 to 0.93. DF and PF 1RM measures were obtained in the prone position through a laboratory-designed device to isolate these muscle groups. The reliability of repeated 1RM testing of DF and PF in our sample was fair to good with ICCs ranging from 0.58 to 0.83.

Bilateral LP and unilateral paretic and nonparetic KE peak muscle power were determined as the highest power achieved from 6 relative intensities of the 1RM by moving the load as fast as possible through the full ROM.¹⁹

Functional Performance

All performance-based functional measures were performed by a single investigator who was blinded to group assignment. The 6-minute walk and the chair-rise test were performed once and the stair-climb and gait velocity tests performed twice with the average used for all analyses.

Six-Minute Walk—Subjects were instructed to cover as much distance as possible within a 6-minute period.²⁰

Stair Climb—Time was recorded to the nearest 0.01 second from first foot contact to final foot placement as subjects ascended a 10-stair flight as quickly and safely as possible.

Chair-Rise—The time it took to move from a starting seated position to standing upright and returning to the seated position 5 times as rapidly as possible with subject's arms across their chest and feet flat on the floor, was recorded to the nearest 0.01 second.²¹

Habitual and Maximal Gait Velocities—Subjects were instructed to walk 10 meters at their normal and maximal velocity, which was assessed using an Ultra timer (DCPB Electronics).²¹

TABLE 1. Baseline Characteristics

Variables	PRT (n=21)	Control (n=21)	P
Age (y)	65.8 (2.5)	66.1 (2.1)	0.92
Time since stroke (mo)	31.8 (3.3)	25.6 (4.0)	0.24
Range	6–60	7–71	
Stroke severity*	2.95 (0.1)	2.97 (0.2)	0.94
Range	2.0–4.4	2.0–4.4	
Depression score†	10.1 (1.3)	10.3 (1.7)	0.90
Medications per day	5.0 (0.6)	5.9 (0.9)	0.40
Assistive device use	12	14	
Ankle foot orthosis use	11	8	
Stroke side	Right=15 Left=6	Right=9 Left=12	

Data represent mean (SE).

*Orpington Prognostic Scale: mild, <3.2; moderate, 3.2 to 5.2.

†GDS: >9 indicates depression of increasing severity.

Self-Reported Function and Disability

The Late-Life Function and Disability Instrument (LLFDI) was used as a comprehensive assessment of 2 disablement constructs: functional limitations (altered ability to perform specific actions encountered in daily routines) and disability (altered performance of major life tasks and social roles).^{22,23} The functional component evaluates self-reported difficulty in performing 32 physical activities, which comprise 3 domains: upper extremity, basic lower extremity, and advanced lower extremity. The disability component evaluates self-reported limitation (capability) and frequency (performance) of taking part in 16 major life tasks. The raw scores from each item response are transformed into linear scaled scores (0 to 100) and subsequently summed to represent component and domain values.

Secondary Outcome Measures

The Geriatric Depression Scale (GDS) was administered to assess depressive symptoms.²⁴ The Sickness Impact Profile (SIP) is a 68-question quality-of-life measure that assesses physical function, mobility, communication, social behavior, and feelings. The Ewart's Self Efficacy Scale measures self-perceived ability for 5 functional tasks.²⁵ The PF 10 was used as a self-reported functional outcome measure and as a baseline screening instrument.²⁶

Statistical Analysis

Data were analyzed with Statview (SAS Institute) and SPSS (SPSS Inc). Intention-to-treat analyses were used for all outcomes. Mean differences between variables at baseline were assessed using unpaired *t* tests. All outcome variables were assessed using analysis of variance for repeated measures. Specific mean differences were assessed using post hoc linear contrasts. Significance was accepted at $P < 0.05$.

Results

Recruitment and Intervention Adherence

One hundred ninety eight individuals completed the telephone-screening questionnaire and 58 underwent medical screening. A total of 42 subjects, 28 men and 14 women, were deemed eligible for participation and randomized into the protocol. There were no significant differences between groups at baseline (Table 1). Two subjects randomized to the control group withdrew during the intervention. Four adverse events occurred during the conduct of the trial. One subject in the PRT group was withdrawn after coronary artery stent

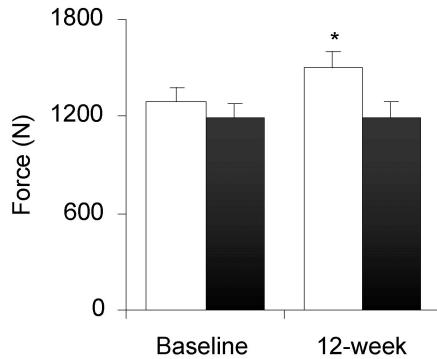


Figure 1. Plot of mean leg press strength \pm SE for the PRT (□, n=21) and control (■, n=21) groups at baseline and week 12. *Significant difference in changes between PRT and control groups after training.

placement unrelated to study participation. Two subjects did not undergo week-12 strength testing due to recurrence of an inguinal hernia (PRT group) and ECG abnormalities (control group). A fourth subject experienced anginal symptoms consistent with coronary artery disease but returned to the study after medical clearance. PRT and control group subjects attended 85.4% and 79.9% of the training visits, respectively.

Outcome Measures

Muscle Strength and Power

There were no baseline differences between groups for LP, paretic KE, or nonparetic KE 1RM or peak power. At baseline, knee extensor strength was reduced 30% on the paretic side compared with the nonparetic side ($P<0.001$, n=24). Lower extremity strength significantly improved in the PRT group for all muscle groups tested with the exception of the nonparetic ankle dorsiflexors (Figures 1 to 3). The PRT group improved 16.2% in LP ($P<0.001$), 31.4% in paretic KE ($P<0.007$), and 38.2% in nonparetic KE ($P<0.001$), with no change in the control group. There was a significant time-by-treatment interaction in the PRT group for paretic DF (66.7%, $P<0.01$), driven by a significant decline in the control (-24.0%, $P<0.03$). Paretic PF (35.5%, $P<0.05$) and

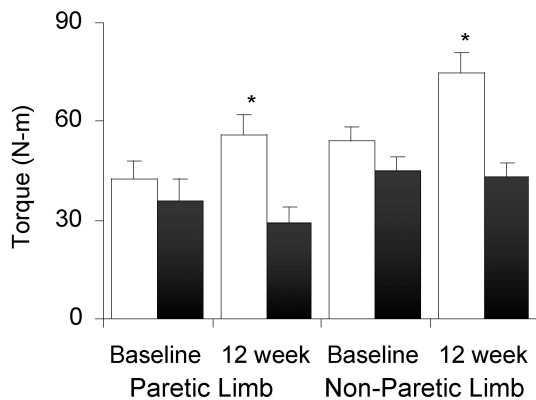


Figure 2. Plot of mean paretic and nonparetic knee extensor strength \pm SE for the PRT (□, n=13, n=21, respectively) and control (■, n=11, n=20, respectively) groups at baseline and week 12.

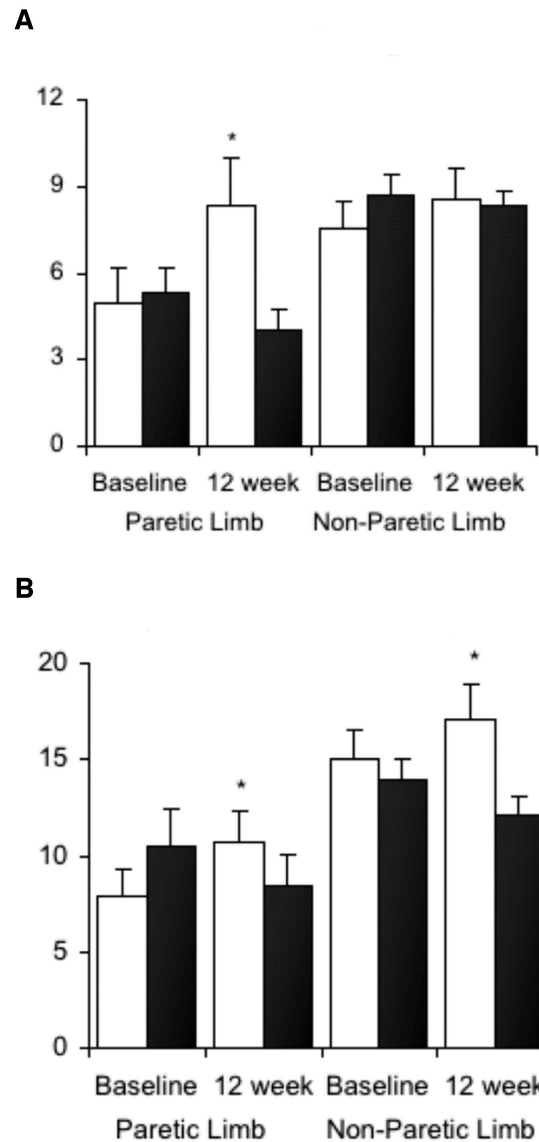


Figure 3. A, Plot of mean paretic and nonparetic ankle dorsiflexor strength \pm SE for the PRT (□, n=13, n=13, respectively) and control (■, n=16, n=16, respectively) groups at baseline and week 12. B, Plot of mean paretic and nonparetic ankle plantarflexion strength \pm SE for the PRT (□, n=13, n=13, respectively) and control (■, n=16, n=16, respectively) groups at baseline and week 12.

nonparetic PF (14.7%, $P<0.01$) significantly improved in the PRT group, and significantly declined over time in the control group (-20.3%, $P<0.02$; -13.8%, $P<0.03$, respectively).

At baseline, KE peak power was reduced by 40% on the paretic side compared with the nonparetic side ($P<0.01$, n=24). In the PRT group, peak power increased 33.0% for paretic KE ($P<0.01$, n=23) and 28.5% for nonparetic KE ($P<0.01$, n=39). LP peak power did not change in the PRT or control interventions.

Functional Performance

There were no significant differences between groups for any performance-based functional measure at baseline or follow-up (Table 2). Six-minute walk time ($P<0.001$) and

TABLE 2. Performance-Based Measures of Function

Physical Performance	Baseline	Week 12	<i>P</i> *
Six-Minute Walk (min)			
PRT (n=21)	217.1 (30.5)	239.1 (30.3)	0.40
Control (n=21)	221.0 (34.0)	234.8 (36.9)	
Stair Climb (sec)			
PRT (n=20)	16.16 (2.49)	15.44 (2.51)	0.76
Control (n=21)	19.26 (2.59)	18.96 (3.07)	
Chair Rise (sec)			
PRT (n=19)	23.14 (1.53)	23.15 (2.72)	0.84
Control (n=19)	27.83 (3.04)	28.51 (4.17)	
Habitual Gait Velocity (m/sec)			
PRT (n=21)	0.65 (0.08)	0.64 (0.08)	0.07
Control (n=21)	0.59 (0.08)	0.64 (0.09)	
Maximal Gait Velocity (m/sec)			
PRT (n=21)	0.84 (0.10)	0.86 (0.11)	0.17
Control (n=21)	0.81 (0.11)	0.87 (0.12)	

*Represents time-by-treatment interactions.

maximal gait velocity ($p < 0.02$) significantly improved in both groups.

Self-Reported Function and Disability

There were no significant baseline differences between groups for any component of the LFFDI. Advanced lower extremity function showed a significant time-by-treatment interaction ($P < 0.04$) favoring the PRT group and driven by a trend to decrease in the control group ($P < 0.06$). The limitation dimension also showed a significant time-by-treatment interaction ($P < 0.05$), though posthoc analysis revealed a trend in the PRT group for change in the limitation dimension ($P < 0.06$) with no change in the control. The instrumental role domain, a subset of the limitation dimension, was significantly improved in the PRT group ($P < 0.02$), with no change in the control group (time-by-treatment interaction $P < 0.05$, Table 3).

Secondary Outcome Measures

There were no significant baseline differences between groups or interactive effects of the intervention for the GDS, SIP, Self-Efficacy Scale, or PF 10. The GDS ($P < 0.02$) and SIP ($P < 0.01$) scores improved in both the PRT and control interventions.

Discussion

The present study demonstrated that a 12-week program of high-intensity PRT can safely improve lower extremity strength and power in both the paretic and nonparetic limbs in long-term stroke survivors, and these improvements are associated with increased self-reported lower extremity function and reduced disability. To our knowledge, this is the first randomized controlled clinical trial to investigate the effects of PRT as the sole therapeutic modality on motor impairments, function, and disability in individuals with long-term stroke.

In the present study, strength significantly increased in all muscle groups targeted by the intervention with the exception of the nonparetic DF. Previous studies have examined the effects of strength training on only the paretic lower extremity after stroke,^{12,14,27} and many have combined strength training with other interventions.^{11,13,14,27} For example, using a 10-week isotonic lower extremity PRT intervention, Teixeira-Salmela et al showed a 42.3% total mean torque improvement in the paretic lower extremity muscle groups trained, including an 18% to 46% gain for paretic KE.¹³ Weiss et al, using a similar PRT intervention to the present study, reported that dynamic paretic KE strength increased 67% and nonparetic KE strength increased 42%.⁷ The present study shows a smaller relative improvement in dynamic strength increase of 31% for paretic KE and a similar change of 38% for nonparetic KE. It is interesting that, in the study by Weiss et al, paretic KE baseline strength was lower than in the present study, but the relative strength improvements were greater.⁷ These differences may reflect the varying

TABLE 3. Late Life Function and Disability Instrument

Function Component	<i>P</i>	Mean PRT Group (SE)		Mean Control Group (SE)	
		Baseline	Week 12	Baseline	Week 12
Function Total (n=41)	0.11	46.5 (1.8)	47.8 (2.1)	49.0 (1.7)	47.8 (2.1)
Upper Extremity (n=41)	0.98	60.3 (2.8)	59.9 (2.5)	60.9 (2.7)	60.4 (2.5)
Basic Lower Extremity (n=41)	0.18	52.7 (2.3)	54.4 (2.7)	55.6 (2.2)	54.4 (2.6)
Advanced Lower Extremity (n=41)	0.03*	29.9 (3.6)	32.7 (3.8)	37.1 (3.5)	33.3 (3.7)
Disability Component					
Frequency Dimension Total (n=41)	0.51	46.7 (1.5)	47.5 (1.7)	47.7 (1.5)	47.4 (1.6)
Social Role (n=41)	0.21	42.0 (1.7)	43.2 (1.7)	42.9 (1.6)	41.6 (1.7)
Personal Role (n=41)	0.55	54.7 (4.3)	56.4 (4.1)	55.9 (4.2)	55.0 (4.0)
Limitation Dimension Total (n=41)	0.05*	54.7 (2.0)	57.1 (2.3)	57.8 (1.9)	55.8 (2.2)
Instrumental Role (n=41)	0.05*	52.2 (2.5)	55.4 (2.6)	57.2 (2.4)	55.0 (2.5)
Management Role (n=41)	0.35	69.0 (2.5)	70.2 (3.9)	67.0 (2.4)	64.5 (3.8)

*Significant time-by-treatment interactions.

degree of stroke severity, the length of time since stroke onset, or the specific exercise training protocol used.

To our knowledge, no other study has examined the effect of resistance training on lower extremity muscle peak power after stroke. Both reductions in peak torque and the rate of torque development are reduced following stroke, suggesting that stroke may be associated with an impaired ability to increase muscle shortening velocity.^{2,3} Given the slow velocity of movement associated with our PRT intervention, it is possible that improvements in force production may have driven these changes in power.

Conflicting evidence exists regarding the effect of lower extremity strength gains on functional performance measures, particularly in studies using resistance training as the sole intervention. In a small sample of chronic stroke survivors, Sharp and Brouwer found a significant increase in habitual gait velocity, with no change in stair climb time or the Timed Up and Go test after isokinetic training of the hemiparetic knee.¹² Weiss et al showed a significant decline in repeated chair-rise time and improved lower extremity function using the Motor Assessment Scale after PRT in chronic stroke survivors; however, habitual gait velocity did not change.⁷ The present study found no changes in functional performance despite improvements in strength and power. Differences in these findings may have resulted from the lack of a placebo control group, sample size and stroke severity differences, or type/duration of the training intervention. Also, it may be that impairments independent of weakness (ie, spasticity or hypertonicity, impaired proprioception, muscle tightness, and muscle imbalances) are responsible for the functional limitations following stroke, and that these factors may not be altered by strength training. Interestingly, improvements in 6-minute walk time and maximal gait velocity were observed across both groups, suggesting that the increased activity level associated with traveling to and from the laboratory 3 times per week may have small, but significant, effects on gait performance.

The present study showed improved LLFDI subscale scores for advanced lower extremity function, the limitation dimension, and the instrumental role domain after PRT. Performance-based functional measures may not be sensitive to change in task-specific functional measures, whereas the LLFDI is able to capture self-perceived changes in physical functioning ability. Moreover, this self-reported functional improvement relates directly to reductions in physical disablement, or socially defined life tasks. It is interesting that no significant change was seen in self-reported frequency of performing life tasks, but that the PRT group felt less limited in performing life tasks at home and in the community. Keysor and Jette have suggested that psychosocial and physical environmental factors may intercede any positive consequences of improved function on disability.²⁸ Nonetheless, the PRT group demonstrated decreased self-reported limitations in performing life tasks. Also, while self-efficacy was not significantly changed between groups, the LLFDI's disability component may capture self-efficacious beliefs through questions addressing capability in performing life tasks. Capability in managing and organizing social tasks (management role domain) did not significantly change,

possibly because these tasks involve more of a cognitive component than the instrumental role domain tasks. More importantly, these changes in self-reported limitation domains specific to the PRT group were independent of the observed improvements in quality of life (SIP) and depressive symptoms (GDS) in both groups, suggesting that this improvement was specific to PRT.

In summary, these findings show that long-term stroke survivors have the capacity to safely improve lower extremity musculoskeletal strength in both the paretic and nonparetic limbs with a program of PRT, and that these improvements lead to reductions in self-reported functional limitations and disability. Future studies are needed to corroborate the present study's results as it is the first randomized controlled trial to investigate the effects of PRT on motor impairments, function, and disability in chronic stroke survivors.

Acknowledgments

The authors would like to thank the study participants who eagerly undertook this project. Funding from The Jacob and Valeria Lange-loth Foundation (to R.A.F).

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