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ORIGINAL REPORT

PROGRESSIVE RESISTANCE TRAINING AFTER STROKE: EFFECTS ON MUSCLE STRENGTH, MUSCLE TONE, GAIT PERFORMANCE AND PERCEIVED PARTICIPATION

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Objective: **To evaluate the effects of progressive resistance training on muscle strength, muscle tone, gait performance and perceived participation after stroke.**
Design: **A randomized controlled trial.**
Subjects: **Twenty-four subjects (mean age 61 years (standard deviation 5)) 6–48 months post-stroke.**
Methods: **The training group (*n* = 15) participated in supervised progressive resistance training of the knee muscles (80% of maximum) twice weekly for 10 weeks, and the control group (*n* = 9) continued their usual daily activities. Both groups were assessed before and after the intervention and at follow-up after 5 months. Muscle strength was evaluated dynamically and isokinetically (60°/sec) and muscle tone by the Modified Ashworth Scale. Gait performance was evaluated by Timed "Up & Go", Fast Gait Speed and 6-Minute Walk tests, and perceived participation by Stroke Impact Scale.**
Results: **Muscle strength increased significantly after progressive resistance training with no increase in muscle tone and improvements were maintained at follow-up. Both groups improved in gait performance, but at follow-up only Timed "Up & Go" and perceived participation were significantly better for the training group.**
Conclusions: **Progressive resistance training is an effective intervention to improve muscle strength in chronic stroke. There appear to be long-term benefits, but further studies are needed to clarify the effects, specifically of progressive resistance training on gait performance and participation.**

Key words: cerebrovascular accident, muscle, skeletal, strength training, gait.

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INTRODUCTION

Reduced muscle strength is a common impairment after stroke (1, 2). As muscle strength is closely related to gait performance, and gait performance is related to perceived participation, after stroke (3, 4), one aim of stroke rehabilitation is to increase muscle strength and thereby improve walking ability and facilitate participation in everyday activities (5, 6). Muscle strength can be increased in several ways after stroke, but the evidence is insufficient to infer that one treatment is more effective than another (7).

An efficient way to increase muscle strength in general is progressive resistance training (PRT), whereby loads of 70% or more of the maximum strength are used (8). PRT induces higher levels of neuromuscular activation than functional exercises, and so is an effective method for improving muscle strength (9). For many years, patients with stroke were advised to avoid resistive exercise training, due to the hypothesized risk of increased muscle tone (10). The evidence that strengthening exercises increases muscle tone is weak (2, 11) and stroke rehabilitation recommendations now include strength training (12, 13). However, there are few randomized controlled studies investigating the effects of PRT in patients after stroke and several questions about the use of PRT remain to be answered.

Ideally, rehabilitation interventions should influence not only function but also activity and participation, defined as persons' lived experiences of involvement in their life situation (14). The effects of strengthening exercises on gait performance and perceived participation have been addressed (11, 15–24), but few studies have evaluated specifically the effects of PRT.

The primary aim of this prospective randomized controlled trial was to assess the effects of PRT on knee muscle strength and muscle tone in subjects with chronic mild to moderate post-stroke hemiparesis. The second aim was to evaluate if changes in muscle strength affect gait performance and if this impacts on perceived participation. The third aim was to determine if any improvements are maintained over time.

MATERIAL AND METHODS

Subjects and study design

The subjects were community dwelling and had been treated over the period 2002–2005 in 1 of the 2 university hospitals in the south

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of Sweden. The inclusion criteria were: (*i*) age between 40 and 70 years; (*ii*) a minimum of 6 months post-stroke (cortical/subcortical); (*iii*) able to perform isolated extension and flexion movements of the knee; (*iv*) at least 15% reduction in muscle strength in the paretic limb (mean isokinetic peak torque at 60º/sec) (to assure a real weakness in the paretic lower limb); (*v*) able to walk without supervision at least 200 m with or without a walking aid; (*vi*) no medication, physical, cognitive or mental dysfunction that could impact upon knee muscle strength, gait performance or perceived participation; and (*vii*) able to understand verbal and written information. The study was approved by the Ethics Research Committee of Lund University, Lund, Sweden (Dnr H4 163/2005).

Potential subjects were identified in the databases at the 2 hospitals. Subjects who were interested in participating and likely to satisfy the inclusion criteria were contacted and received information about the study. Prior to the first test session, all subjects gave written informed consent, completed a questionnaire providing demographic and medical information, and were medically checked. Subjects who satisfied the inclusion criteria were stratified by sex and randomized to a training group (TG) or a control group (CG) (ratio 2:1). The subjects were included consecutively into the study and randomized (non-sealed envelopes) into the TG or CG. All subjects were provided transport free of charge to and from the hospital during testing and training.

Outcome measurements

To cover all domains in the International Classification of Functioning, Disability and Health (ICF) (14), dynamic and isokinetic muscle strength, muscle tone, gait performance and perceived participation were assessed. All measurements were made before and after the intervention, and at follow-up 5 months after the intervention.

Dynamic knee muscle strength

Knee extension and knee flexion dynamic strength in the paretic and non-paretic lower limb were determined for each subject using a Leg Extension/Curl Rehab exercise machine with pneumatic resistance (pressure resistance 10 bar) (HUR Ltd, Kokkola, Finland). The load that could be moved through a comfortable range of motion (ROM) 6 times but not more than 8 times was considered equivalent to 80% of the maximum load. Each value was used to set the training load and as the baseline value in the evaluation of the intervention. For the TG the loads were adjusted every second week (4 times during the intervention) and the final loads were used to evaluate changes in dynamic strength. For the CG, the same procedure was followed, separated by 10 weeks. For both groups the procedure was repeated at follow-up.

Isokinetic knee muscle strength

Isokinetic concentric knee extension and flexion strength at 60º/sec were measured with a Biodex® Multi-Joint System 3 PRO dynamometer (Biodex Medical Systems, Inc., New York). Before each measurement the full ROM was set and the Biodex software applied the gravity correction. Each subject performed 3 maximal concentric extension and flexion contractions with the non-paretic lower limb, and the highest peak torques were recorded (Newton meter; Nm). The same test procedure was repeated with the paretic lower limb. Throughout the tests, subjects sat with their arms folded and were verbally encouraged to push and pull as hard and as fast as possible. The velocity (60º/sec) was chosen as it has been found to be highly reliable in patents after chronic stroke (intraclass correlation coefficient, ($ICC_{2,1}$), 0.89–0.94; standard error of measurement (SEM%), 9–17%) (25).

Muscle tone

Increased muscle tone in the paretic lower limb was assessed with the Modified Ashworth scale (MAS) (26). The MAS is a 6-point rating scale, ranging from 0 (no increase in tone) to 5 (the limb is rigid). The tested muscle groups were: hip adductors, hip extensors and flexors, knee extensors and flexors and ankle dorsiflexors and plantar flexors (maximal score 35).

Gait performance

Gait performance was assessed by 3 tests in the following order: Timed "Up & Go" (TUG), Fast Gait Speed (FGS), and 6-Minute Walk (6MW) tests. All tests were performed in a corridor separate from the training area. Subjects were allowed to use, if needed, their ankle-foot orthosis and their assistive device. A digital stopwatch with an accuracy of 1 decimal figure in units of 1 sec was used to measure time. These gait performance tests have been found to be highly reliable in patients after chronic stroke ($ICC_{2,1}$ 0.96–0.99; SEM% < 9%) (27).

For the TUG, subjects were instructed to sit with their back against a chair, and on the word "go", stand up, walk at a comfortable speed past a 3 m mark, turn around, walk back and sit down in the chair. The TUG was carried out twice, with 1 min between each trial, and the mean time (in sec) of these 2 trials was recorded.

For the FGS, subjects were timed over the middle 10 m of a 14-m marked distance. The subjects were told to walk as fast and safely as possible without running. The FGS test was done 3 times in succession, with 30 sec between each trial. The time (in sec) over 10 m was recorded for each trial and the mean time for the 3 trials was calculated.

For 6MW, subjects were instructed to walk 30 m between 2 floor marks, and after passing either mark, they were told to turn and walk back. Subjects were instructed to walk as far as possible during a period of 6 min. The distance covered was measured to the nearest metre and these values were used in the statistical analyses.

Perceived participation

Perceived participation was assessed by the Stroke Impact Scale 3.0 (28) (SIS; Swedish version). SIS is a self-report questionnaire that assesses aspects of the impact of a stroke on an individual's self-perceived health. Items in 8 domains are scored on a 5-grade scale from 5 (limited none of the time) to 1 (limited all of the time) and the mean for each domain is calculated. SIS has been shown to be both valid and reliable (29) and has been used to assess the relationship between gait performance and perceived participation (4).

Only the SIS Participation domain was used here. SIS Participation addresses the impact of stroke on: work; social activities; quiet recreations; active recreations; role as a family member; religious activities; life control; and ability to help others. For each subject, the mean score of these 8 items was calculated and converted into a percentage (0–100) value (28): 100 × (the mean value of the 8 items –1)/(5–1). High values represent no or few restrictions in participation and low values indicate more restricted participation.

Blinding

Two physiotherapists, blinded to the group assignment of the subjects, assessed isokinetic strength, and gait performance and perceived participation, respectively, at the 3 test-sessions. Dynamic strength and muscle tone were assessed by the responsible physiotherapist (UBF), who knew the group assignment of each subject. The subjects were not blinded to their group assignment and were told not to discuss the group assignment with the blinded assessors.

Intervention and follow-up

The TG participated in 10 weeks of PRT twice weekly using the Leg Extension/Curl Rehab exercise machine (see above). All exercise was performed individually and supervised by the responsible physiotherapist (UBF). Each training session started with a warm-up of 5 min of stationary cycling, 5 repetitions (reps) without resistance and 5 reps at 25% of their maximum load. The subjects then performed 6–8 reps in 2 sets at a low speed (30–40 sec/set) with about 80% of their maximum load and with a 2-min rest between each set. The subjects performed as many reps as possible on each occasion and every 2 weeks the load was adjusted to remain at 80% of their maximum load. The extensors in the non-paretic lower limb were trained followed by the extensors in the paretic lower limb. After a 10-min rest, the same procedure was repeated with the flexors in the non-paretic and paretic lower limbs. After each training session, the knee extensors and flexors were passively stretched using a static technique (30). Each training session lasted about 90 min, but the actual PRT time was less than 6 min. Between each training session, subjects continued their usual daily activities and other forms of training but were not engaged in any PRT. After the 10-week intervention, subjects were asked about their experiences of the PRT. The CG was encouraged to continue their usual daily activities and training but not to engage in any PRT. They were afterwards asked about their activities during the 10-week intervention.

Following the 10-week intervention, all subjects in both groups were instructed to continue their usual daily activities and other forms of training, but to refrain from PRT. At follow-up, all subjects were asked about their activities and any medical issues during the interim.

Statistics

Prior to the study, a power analysis was done using data from the previous reliability studies (25, 27). To achieve a power of 80% and 5% significance level, 17 subjects in the TG and CG were required. To include as many subjects as possible in the TG without unduly compromising the statistical power, the number of subjects in the CG was reduced to give a ratio TG vs CG of approximately 2:1; the power was then 77% (31).

The changes between baseline and after intervention, and between baseline and follow-up, were calculated for each subject together with the percentage differences for the mean of each measurement. Baseline values between the TG and CG were assessed with the two-tailed *t*-test for continuous variables, the Mann-Whitney *U* test for ordered variables and Fisher's exact test for dichotomous variables. Differences between the TG and CG after intervention and at follow-up were assessed with a general linear model (GLM) for repeated measurements followed by the *t*-test and the Mann-Whitney *U* test for ordered variables. Within the TG and CG the differences between the 3 test-sessions were tested with the paired *t*-test except for MAS, where the Wilcoxon's sign rank test was applied. The relationships between the percentage changes after PRT in relation to their baseline values were assessed by Pearson's correlation coefficient. All statistical tests were two-tailed.

All calculations were performed using the SPSS 11.0 Software for Windows. Significance levels less than 0.05 represented statistical significance, whereas values greater than 0.05 were considered not significant. The normality assumptions were assessed by the Kolmogorov-Smirnov test and were never rejected.

RESULTS

Subject characteristics

Of the 133 subjects identified as potential participants, 35 were considered eligible and gave informed consent to participate in the study (Fig. 1). A total of 25 met the inclusion criteria, were accepted for the study and randomized into either the TG (n = 16) or the CG (n = 9). There was one drop-out from the TG due to an accident unrelated to the PRT and this subject was excluded from the statistical analyses. For comparison an intention-to-treat analysis was performed with the drop-out subject included, but this did not change the inferences. There were no significant differences between the 2 groups at baseline. A summary of the clinical characteristics for the TG (n = 15) and the CG (n = 9) is presented in Table I.

General outcome

The TG attendance rate was 98%, which compares well with rates in other stroke training studies (85–100%) (20–22).

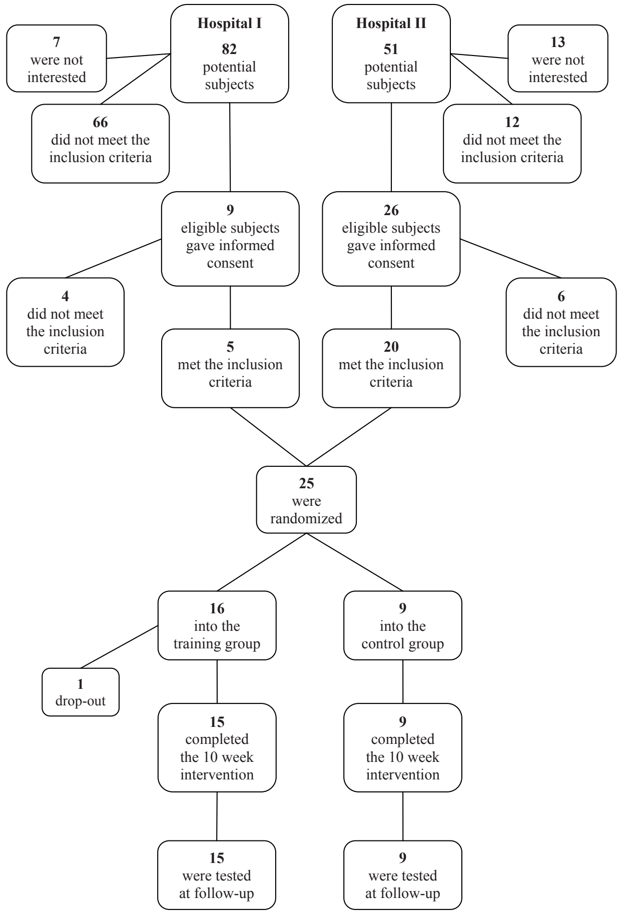

Fig. 1. Study flow-chart.

At the start of the study all subjects reported some physical activity and no subjects were engaged in interdisciplinary rehabilitation. Subjects in the CG reported no discernible quantitative or qualitative changes in their physical activity pattern during the study. No injuries occurred during the training sessions and the subjects described very low or no discomfort during or after the sessions. The subjects in the TG reported subjective improvements in strength, endurance and balance, positive effects of the stretching and a general

Table I. *Subjects clinical characteristics at baseline*

Variable	Training group (n = 15)	Control group (n = 9)
Age, years (mean (SD))	61 (5)	60 (5)
Time since stroke onset, months (mean (SD))	18.9 (7.9)	20.0 (11.6)
Sex, n (men/women)	9/6	5/4
Paretic side, n (right/left)	7/8	1/8
Type of stroke, n (ischaemic/haemorrhagic)	12/3	6/3
Assistive device use, n	4	3
Ankle foot orthosis use, n	3	1

There was no significant difference for any variable at baseline.
SD: standard deviation

increase in self-esteem and life satisfaction. The importance of the encouragement and support provided by other TG subjects, attending the training sessions, was consistently raised afterwards.

Dynamic knee muscle strength

In Table II, the mean values before, after and at follow-up are presented, together with the between-group differences. For the TG, dynamic strength increased significantly after the intervention and at follow-up (+34% to +70%; $p < 0.001$) for both the paretic and non-paretic lower limb. For the CG, dynamic strength increased significantly (+8% to +9%; $p < 0.05$) after the intervention for the non-paretic lower limb, but not for the paretic, and at follow-up only non-paretic flexion was significantly higher (+8%; $p < 0.05$) than at baseline. There were no significant differences between the TG and CG at baseline, but a significant difference after the intervention ($p < 0.001$) and at follow-up ($p < 0.001$).

Isokinetic knee muscle strength

In Table II, the mean values before, after and at follow-up are presented, together with the between-group differences. The mean percentage isokinetic weakness at baseline (paretic vs non-paretic limb) for the extensors and flexors was 59% ± 22 for the TG and 58% ± 27 for the CG. For the TG, isokinetic strength increased significantly for both lower limbs after the intervention and at follow-up (+14% to +73%; $p < 0.01$). For the CG, there were no significant changes after the intervention or at follow-up (–1% to + 24%). There were no significant differences between the TG and CG at baseline, but a significant difference ($p < 0.05$) after the intervention for non-paretic extension and flexion, and at follow-up for non-paretic extension.

Muscle tone

Subjects in both the TG and CG had low or no increased muscle tone at baseline (median 2, 0/8). Muscle tone was significantly lower after the intervention in the TG (median 1, 0/7; $p < 0.01$) and CG (median 0, 0/4; $p = 0.02$). At follow-up there was no significant change compared with baseline (median 1.5; 0/10). There was no significant difference between the TG and CG at baseline, after the intervention and at follow-up.

Gait performance

In Table III, the mean values before, after and at follow-up are presented, together with the between-group differences. The mean value for TUG in healthy individuals is 8 sec, for FGS 5 sec and for 6MW 553 m (32).

For the TG, all gait performance tests improved significantly ($p < 0.05$) after the intervention (+10% to +19%) and for TUG and 6MW at follow-up (+10% to +18%). For the CG, only TUG improved significantly (+10%; $p < 0.05$) after the intervention. There were no significant differences between the TG and CG at baseline or after the intervention, but at follow-up for TUG ($p < 0.05$).

For the TG there was a significant relationship between baseline and the percentage change after intervention in 6MW ($r = –0.53$; $p < 0.05$): subjects who performed less well at baseline had a greater percentage improvement in 6MW.

Perceived participation

In Table IV, the mean values before, after and at follow-up are presented, together with the between-group differences. There was no significant difference between the TG and CG at baseline or after the intervention but at follow-up ($p < 0.05$): for the TG, the SIS value at follow-up was 1% higher than at baseline, whereas for the CG the SIS value was 19% lower than at baseline.

Table II. *Dynamic and isokinetic knee muscle strength before, after and at follow-up. All values are presented as means with standard deviations in parentheses*

	Training group (TG) ($n = 15$)			Control group (CG) ($n = 9$)			Differences between groups†	
	Before	After	Follow-up	Before	After	Follow-up	Before vs after	Before vs follow-up
Dynamic								
Extension								
Non-paretic (Nm)	64.4 (14.1)	92.6 (21.3)	89.1 (20.5)	60.8 (20.7)	65.3 (22.5)	63.2 (22.6)	23.6 (3.4)**	22.3 (3.6)**
Paretic (Nm)	41.0 (13.6)	63.1 (19.6)	59.4 (22.6)	40.1 (18.7)	41.3 (20.9)	42.0 (20.1)	21.0 (3.2)**	16.5 (3.4)**
Flexion								
Non-paretic (Nm)	81.1 (20.1)	113.2 (25).9	108.4 (25.1)	77.8 (26.1)	83.7 (25.6)	84.3 (26.1)	26.2 (4.3)**	20.7 (3.8)**
Paretic (Nm)	43.5 (19.5)	74.0 (27.7)	70.6 (26.7)	50.7 (19.2)	53.5 (21.1)	53.0 (22.1)	27.7 (3.6)**	24.7 (4.1)**
Isokinetic								
Extension								
Non-paretic (Nm)	119.3 (38.8)	135.9 (33.5)	137.6 (40.5)	119.4 (40.5)	118.4 (38.0)	118.7 (36.7)	17.6 (8.5)*	19.2 (8.9)*
Paretic (Nm)	64.2 (31.1)	77.9 (34.0)	76.3 (34.6)	58.6 (35.3)	58.8 (28.2)	61.7 (30.6)	13.5 (6.6)	9.0 (6.2)
Flexion								
Non-paretic (Nm)	54.0 (19.0)	65.5 (19.6)	61.3 (18.9)	55.9 (26.0)	58.7 (27.7)	56.1 (22.7)	8.7 (4.2)*	7.0 (3.8)
Paretic (Nm)	15.3 (19.0)	25.2 (22.5)	26.5 (24.8)	16.1 (15.7)	19.5(16.6)	20.0 (14.1)	6.4 (4.1)	7.3 (5.2)

†Differences between groups are calculated from the mean changes for each group (TG minus CG).
$^*p < 0.05$, $^{**}p > 0.001$.

Table III. *Gait performance before, after and at follow-up. All values are presented as means with standard deviations in parentheses.*

	Training group (TG) (n = 15)			Control group (CG) (n = 9)			Difference between groups*	
Gait performance	Before	After	Follow-up	Before	After	Follow-up	Before vs after	Before vs follow-up
TUG (sec)	28.6 (13.9)	23.1 (10.3)	23.6 (11.1)	26.9 (15.2)	24.3 (14.2)	26.7 (18.9)	2.9 (1.4)	4.9 (2.0)†
FGS (10m; sec)	18.0 (10.3)	15.4 (8.8)	16.1 (9.9)	18.7 (15.4)	17.9 (15.3)	19.4 (17.8)	1.9 (1.2)	2.7 (2.0)
6MW (m)	228.0 (137.0)	250.0 (131.0)	251.0 (144.0)	234.0 (134.0)	247.0 (142.0)	240.0 (140.0)	9.0 (10.0)	17.0 (14.0)

†$p < 0.05$.
*Differences between groups are calculated from the mean changes for each group (TG minus CG).
TUG: timed "up & go"; FGS: fast gait speed; 6MW: 6-minute walk test.

Relationships between the outcome measurements

For the TG, there were significant relationships after the intervention between the percentage changes for FGS and SIS ($r = -0.63$; $p < 0.05$) and for 6MW and SIS ($r = 0.74$; $p < 0.01$), indicating that improvements in gait performance were related to improvements in perceived participation. No such relationships were found for the CG.

DISCUSSION

As muscle weakness is a common impairment after stroke, interventions that can improve muscle strength are an important part of stroke rehabilitation (3). The aim of the present study was to evaluate the effects of PRT on muscle strength, muscle tone, gait performance and perceived participation after stroke. We found that PRT improved knee muscle strength in the lower limbs without any negative effects on muscle tone, that improvements in strength were maintained at follow-up, that improved strength did not lead to improved gait performance and participation after intervention but that long-term differences in favour of the TG were present at follow-up.

Effects on muscle strength and muscle tone

Both dynamic and isokinetic knee muscle strength increased significantly after PRT. The subjects in the TG had a clear muscle weakness in the paretic limb and the results indicate that strength training can reduce this weakness even in quite affected post-stroke individuals. As the percentage increase for isokinetic strength was lower than for dynamic strength, the differences between the TG and CG were only significant for the non-paretic lower limb. This highlights the well-known difference between dynamic and isokinetic training and testing, which is thought to be due to neural adaptations specific to the type of training and testing (33).

The improvements in muscle strength are comparable with previous studies of chronic post-stroke subjects. The improvements in dynamic knee muscle strength following PRT have varied between 24% and 38% (18, 19, 21) compared with 41% to 75% in this study, and between 17% and 130% for isokinetic knee muscle strength at 60º/sec (15, 16, 20, 22) compared with 14–64% here.

Increases in strength were well maintained at follow-up and all measurements in the TG were significantly higher than at baseline. One study has evaluated the long-term effects of strength training (16). Four weeks after a 6-week non-controlled isokinetic strengthening program, isokinetic knee muscle strength at 60º/sec was not significantly different from baseline.

The subjects in the present study had low or no increased muscle tone at baseline and no increase was detected after PRT – muscle tone actually decreased significantly and remained low throughout the study. This finding is consistent with spasticity being rare in hemiparetic stroke patients with mild to moderate disability (34) and PRT having no negative effect on muscle tone (16–19).

Effects on gait performance

The effects of PRT on gait performance are less clear than the effects on strength (11). Positive effects on gait speed and endurance have been demonstrated in some studies (15–17, 19, 23) but not in others (20–22, 24).

Table IV. *Perceived participation (Stroke Impact Scale) before, after and at follow-up. All values are presented as means with standard deviations in parentheses.*

	Training group (TG) (n = 15)			Control group (CG) (n = 9)			Difference between groups*	
	Before	After	Follow-up	Before	After	Follow-up	Before vs after	Before vs follow-up
Stroke Impact Scale Participation (%)	54.2 (20.0)	58.8 (19.5)	54.8 (17.9)	61.1 (21.8)	57.3 (19.3)	49.3 (20.1)	8.4 (8.7)	12.4 (5.7)†

†$p < 0.05$.
*Differences between groups are calculated from the mean changes for each group (TG minus CG).

In the present study, subjects in both groups improved to a similar extent in gait performance after intervention. Thus, improvements specifically in knee muscle strength did not seem to affect gait performance more than other forms of training (24).

It was noted that the subjects in the TG who performed less well at baseline had a greater improvement in 6MW. The relationship between muscle strength and functional skills has been described as curvilinear. If strength is sufficient to perform an activity, further improvements in strength may not lead to any substantive gains (35), which may explain the larger improvements in gait performance after PRT achieved by the slow walkers in this study.

To the best of our knowledge, this is the first study that has evaluated the effects of progressive resistance training on functional parameters several months after the intervention. Interestingly, at follow-up all improvements in the CG had returned to baseline, whereas improvements in the TG were maintained, and a statistical between-group difference for TUG was now found. This could indicate a long-term effect of PRT on aspects of gait performance that is not evident until several months after an intervention. The improvement in absolute terms was small, but as the subjects were considered to be slow walkers even a mean improvement of 5 sec in TUG could be important in their daily life. An interesting area for future research is to explore the magnitude of improvements and how that corresponds to what patients, clinicians and scientists judge as clinically meaningful.

Effects on perceived participation

PRT did not affect perceived participation. However, as several subjects in the CG continued to decline during the study, this led to a significant difference between the TG and CG at follow-up. Furthermore, improvements in FGS and 6MW in the TG were significantly related to improvements in SIS after the intervention. Whether this indicates a long-term benefit of PRT on perceived participation, and that enhanced gait performance might influence perceived participation is not entirely clear. As for improvements in TUG, further studies are needed to explore whether this is clinically meaningful. Previous studies have not directly addressed the influence of improvements in gait performance on perceived participation. Overall physical activity has been measured and some improvements after PRT were reported (16, 17, 22). Ouellette et al. (21) evaluated changes in function and disability after PRT and found that self-reported limitations in performing life tasks decreased following PRT, indicating a beneficial effect on measures of perceived participation. As participation is an important outcome after stroke and it is a fairly new term, this area of stroke rehabilitation holds potential for future research.

Limitations

The number of participating subjects was relatively small, which affected the statistical power and some of the lack of significance between the TG and CG could be due to this reduced power. There was difficulty recruiting enough eligible participants, because many of the contacted subjects who expressed an interest were either unable to walk or were too strong in the paretic lower limb. Even if equal-sized groups provide the most efficient means to compare treatments, there is only a small loss of power by using ratio 2:1 (31).

Only the knee muscles were trained here. Weakness in other muscle groups, such as hip and ankle muscles, as well as other physical impairments, such as postural control, coordination, balance and sensorimotor function, can influence gait performance after stroke. Even though knee muscle strength alone can explain up to 50% of the variance of gait performance (4), gait performance may be further enhanced if PRT is part of a composite training program (24). In addition, the duration of the PRT, only 10 weeks, might have been too short and a longer period could have resulted in larger strength improvements and thereby greater differences in gait performance and perceived participation between the groups.

Many subjects in the TG expressed benefits from the PRT that was not always reflected in the outcome measurements used. A qualitative approach might allow us to embrace a wider perspective of health by exploring the subjects' own perception of PRT and its influence on their everyday activities, and thereby assist us in considering other appropriate outcome measurements.

As all subjects in this study were relatively young and more than 6 months post-stroke, additional studies are required to determine the effects of PRT for older subjects and sooner after the onset of stroke. Further studies are also needed to understand the underlying mechanisms of the increased muscle strength.

In summary, 10 weeks of PRT improved knee muscle strength in chronic post-stroke subjects with mild to moderate weakness without compromising muscle tone, but there were no immediate effects on gait performance. Improvements in muscle strength were maintained and some beneficial effects on gait performance and perceived participation were seen at follow-up. Thus, PRT is an effective form of training that can improve muscle strength in chronic stroke patients several years after stroke onset. Its use specifically as a physiotherapy treatment or as fitness training in order to improve gait performance and participation remains unclear.

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REFERENCES

1. Ng SM, Shepherd RB. Weakness in patients with stroke: Implications for strength training in neurorehabilitation. Phys Ther Rev 2000; 5: 227–238.
2. Patten C, Lexell J, Brown HE. Weakness and strength training in persons with post-stroke hemiplegia: rationale, method and efficacy. J Rehabil Res Dev 2004; 41: 293–312.
3. Bohannon RW. Muscle strength and muscle training after stroke. J Rehabil Med 2007; 39: 14–20.
4. Flansbjer UB, Downham D, Lexell J. Knee muscle strength, gait performance, and perceived participation after stroke. Arch Phys Med Rehabil 2006; 87: 974–980.
5. Richards CL, Malouin F, Dean C. Gait in stroke: assessment and rehabilitation. Clin Geriatr Med 1999; 15: 833–855.
6. Parker CJ, Gladman JR, Drummond AE. The role of leisure in stroke rehabilitation. Disabil Rehabil 1997; 19: 1–5.
7. Pollock A, Baer G, Pomeroy VM, Langhorne P. Physiotherapy treatment approaches for the recovery of postural control and lower limb function following stroke. The Cochrane Database of Systematic Reviews Library 1999: Art. No.: CD003316.
8. Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. Med Sci Sports Exerc 2004; 36: 674–688.
9. Andersen LL, Magnusson SP, Nielsen M, Haleem J, Poulsen K, Aagaard P. Neuromuscular activation in conventional therapeutic exercises and heavy resistance exercises: implications for rehabilitation. Phys Ther 2006; 86: 683–697.
10. Bobath B, editor. Adult hemiplegia: evaluation and treatment. 2nd edn. London, England: Heinemann; 1978.
11. Morris SL, Dodd KJ, Morris ME. Outcomes of progressive resistance strength training following stroke: a systematic review. Clin Rehabil 2004; 18: 27–39.
12. Gordon NF, Gulanick M, Costa F, Fletcher G, Franklin BA, Roth EJ, et al. Physical activity and exercise recommendations for stroke survivors: an American Heart Association scientific statement from the Council on Clinical Cardiology, Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention; the Council on Cardiovascular Nursing; the Council on Nutrition, Physical Activity, and Metabolism; and the Stroke Council. Circulation 2004; 109: 2031–2041.
13. National guidelines for stroke, second edn. London: Royal Colleges of Physicians of London; 2004.
14. International classification of functioning, disability and health: ICF. Geneva: World Health Organization; 2001.
15. Engardt M, Knutsson E, Jonsson M, Sternhag M. Dynamic muscle strength training in stroke patients: effects on knee extension torque, electromyographic activity, and motor function. Arch Phys Med Rehabil 1995; 76: 419–425.
16. Sharp SA, Brouwer BJ. Isokinetic strength training of the hemiparetic knee: effects on function and spasticity. Arch Phys Med Rehabil 1997; 78: 1231–1236.
17. Teixeira-Salmela LF, Olney SJ, Nadeau S, Brouwer B. Muscle strengthening and physical conditioning to reduce impairment and disability in chronic stroke survivors. Arch Phys Med Rehabil 1999; 80: 1211–1218.
18. Badics E, Wittmann A, Rupp M, Stabauer B, Zifko UA. Systematic muscle building exercises in the rehabilitation of stroke patients. NeuroRehabilitation 2002; 17: 211–214.
19. Bourbonnais D, Bilodeau S, Lepage Y, Beaudoin N, Gravel D, Forget R. Effect of force-feedback treatments in patients with chronic motor deficits after a stroke. Am J Phys Med Rehabil 2002; 81: 890–897.
20. Kim CM, Eng JJ, MacIntyre DL, Dawson AS. Effects of isokinetic strength training on walking in persons with stroke: a double-blind controlled pilot study. J Stroke Cerebrovasc Dis 2001; 10: 265–273.
21. Ouellette MM, LeBrasseur NK, Bean JF, Phillips E, Stein J, Frontera WR, et al. High-intensity resistance training improves muscle strength, self-reported function, and disability in long-term stroke survivors. Stroke 2004; 35: 1404–1409.
22. Weiss A, Suzuki T, Bean J, Fielding RA. High intensity strength training improves strength and functional performance after stroke. Am J Phys Med Rehabil 2000; 79: 369–376.
23. Ada L, Dorsch S, Canning C. Strengthening interventions increase strength and improve activity after stroke: a systematic review. Aust J Physiother 2006; 52: 241–248.
24. van de Port IG, Wood-Dauphinee S, Lindeman E, Kwakkel G. Effects of exercise training programs on walking competency after stroke: a systematic review. Am J Phys Med Rehabil 2007 Feb 12; [Epub ahead of print].
25. Flansbjer U-B, Holmbäck AM, Downham D, Lexell J. What change in isokinetic knee muscle strength can be detected in men and women after stroke? Clin Rehabil 2005; 19: 514–522.
26. Blackburn M, van Vliet P, Mockett SP. Reliability of measurements obtained with the modified Ashworth scale in the lower extremities of people with stroke. Phys Ther 2002; 82: 25–34.
27. Flansbjer U-B, Holmbäck AM, Downham D, Patten C, Lexell J. Reliability of gait performance tests in men and women with hemiparesis after stroke. J Rehabil Med 2005; 37: 75–82.
28. Duncan PW, Wallace D, Lai SM, Johnson D, Embretson S, Laster LJ. The stroke impact scale version 2.0. Evaluation of reliability, validity, and sensitivity to change. Stroke 1999; 30: 2131–2140.
29. Edwards B, O'Connell B. Internal consistency and validity of the Stroke Impact Scale 2.0 (SIS 2.0) and SIS-16 in an Australian sample. Qual Life Res 2003; 12: 1127–1135.
30. Whaley MH, Brubaker PH, Otto RM, Armstrong L, Balady GJ, Berry MJ, et al, editors. ACSM's guidelines for exercise testing and prescription seventh edition edn. American College of Sport Medicine. Philadelphia: Lippincott Williams & Wilkins; 2006.
31. Pocock SJ. Allocation of patients to treatment in clinical trials. Biometrics 1979; 35: 183–197.
32. Steffen TM, Hacker TA, Mollinger L. Age- and gender-related test performance in community-dwelling elderly people: Six-Minute Walk Test, Berg Balance Scale, Timed Up & Go Test, and gait speeds. Phys Ther 2002; 82: 128–137.
33. Sale DG. Neural adaptation to resistance training. Med Sci Sports Exerc 1988; 20: S135–S145.
34. Sommerfeld DK, Eek EU, Svensson AK, Holmqvist LW, von Arbin MH. Spasticity after stroke: its occurrence and association with motor impairments and activity limitations. Stroke 2004; 35: 134–139.
35. Buchner DM, Beresford SA, Larson EB, LaCroix AZ, Wagner EH. Effects of physical activity on health status in older adults. II. Intervention studies. Annu Rev Public Health 1992; 13: 469–488.