Progressive Resistance Strengthening Exercises After Stroke: A Single-Blind Randomized Controlled Trial

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Objective: To determine the effectiveness of progressive resistance strengthening exercises to improve gross motor function and walking in patients receiving intensive rehabilitation after stroke.

Design: Randomized controlled trial.

Setting: Five inpatient rehabilitation programs affiliated with teaching hospitals.

Participants: Inclusion criteria included less than 6 months poststroke and recovery of the leg stages 3 to 5 on the Chedoke-McMaster Stroke Assessment (CMSA).

Interventions: Both groups received conventional physical therapy programs. In addition, the experimental group performed 9 lower-extremity progressive resistance exercises 3 times a week for the duration of their stay, whereas the control group did the same exercises and for the same duration but without resistance.

Main Outcome Measures: The Disability Inventory of the CMSA and the 2-minute walk test (2MWT) at baseline, 4 weeks, discharge, and 6 months after discharge.

Results: Over the length of stay, the rate of change in the Disability Inventory was .27 points per day in the experimental group and .29 points per day in the control group; the between-group difference was −.02 points per day (95% confidence interval [CI], −.10 to .06; P=.62). At discharge, the rate of change in the 2MWT was −.01m in the experimental group and .15m in the control group; the between-group difference was −.16m (95% CI, −.37 to .05; P=.14).

Conclusions: Progressive resistance strengthening exercises as applied in our study were not effective when compared with the same exercises given without resistance.

Key Words: Cerebrovascular accident; Exercise; Randomized controlled trials; Rehabilitation.

PETRASOVITS AND NAIR[1] reported that stroke is a major cause of disability and economic cost. An analysis of Canada's National Health Population Survey found that 87% of people with stroke had restriction in their activities of daily living (ADLs) and that 42% had mobility problems.[2] One objective of rehabilitation after stroke is to maximize the patient's independence in gross motor skills and walking and thus improve his/her ADLs. In patients with stroke, research on muscle weakness, the correlation of muscle strength with function, and studies on the effects of strength training suggest that strengthening exercises may improve functional outcomes.

Bourbonnais and Vanden Noven[3] and Giuliani[4] have summarized the studies of physiologic changes in stroke patients. These changes include denervation potentials, loss of motor units, selective atrophy of type II muscle fibers, impaired motor unit recruitment, and decreased maximal contractions. The overall contraction time has been found to be prolonged, and some studies have shown a decrease in the motor unit firing rate. All of these factors can contribute to muscle weakness.

Although some studies have shown that the force of prime movers may be impaired by inappropriate activation of antagonist muscles,[5,6] other studies do not support this finding. Gowland et al[7] studied 6 upper-extremity movements and found inadequate muscle recruitment, as opposed to increased activity, in the antagonist muscles. Whitley et al[8] and Sahrmann and Norton[9] also concluded that both a lack of electromyographic activity and incoordination, rather than antagonist spasticity or cocontraction, were responsible for movement impairment. Although the elbow flexors have traditionally been thought to be spastic and hence stronger in hemiparetic patients, Colebatch et al[10] observed that they were weaker than the extensors. In studying standing balance, Di Fabio[11] found that the antagonist muscle response was often absent or attenuated when balance was disturbed. Therefore, contrary to previous beliefs, both the agonists and antagonists may be weak in hemiparetic patients. Using a handheld dynamometer, Andrews and Bohannon[12] found that muscle strength in stroke patients who were undergoing inpatient rehabilitation was 20% to 34% of normal on the affected side and 60% to 89% of normal on the unaffected side.

Several cross-sectional studies have found significant correlations between muscle force and functional performance.[13-23] Although a consistent relation between strength and function has been identified, experimental studies are needed to establish a causal relation.

We identified 4 studies of progressive resistance exercise training in patients with stroke.[24-27] Inaba et al[24] randomized 176 patients into 3 groups: functional training and stretching; active exercise plus functional training and stretching; and

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progressive resistive exercise plus functional training and stretching. The resistive exercise group improved significantly more in strength and gross motor function at 1 month, although the differences were not statistically significant at 2 months. Due to loss to follow-up (56% loss), there may have been substantial biases that influenced the results. A definitive conclusion could not be reached because of the study's methodologic shortcomings.

Engardt et al[25] studied the responses of 20 patients with hemiparesis to eccentric and concentric isokinetic training for knee extension. The subjects were allocated to the 2 groups by matching their clinical characteristics. The eccentric group was superior ($P<.05$) to the concentric group in improvement toward symmetrical body weight distribution when standing from sitting. A major limitation of this study was the lack of a control group.

Sharp and Brouwer[26] completed a pretest-posttest cohort study of 15 individuals with stroke of more than 6 months in duration who did isokinetic strength training for 6 weeks. They found statistically significant changes in peak torque of the knee extensors and the knee flexors, walking speed, and the Human Activity Profile (a subjective measure of activity). This study was important because it found that spasticity did not increase with muscle strengthening exercises. The lack of a control group limits interpretation of the findings because patients with long-standing stroke are known to improve under the conditions of practice.[28] In another uncontrolled study of patients with long-standing stroke, Weiss et al[27] evaluated the effects of progressive resistance strength training on both the affected and least affected sides. Strength improved by 68% on the affected side and 48% on the least affected side. Results as measured by repeated chair stands, the Motor Assessment Scale, and the Berg Balance Scale also improved; however, it cannot be ruled out that these improvements resulted from the strengthening on the least affected side. Again, the lack of a control group limits the interpretation of this study.

Other studies[29-31] have combined strength training with other types of therapy; therefore, the effect of only the strength training cannot be determined. Overall, the effects of progressive resistance exercises have not been sufficiently examined to guide practice in the rehabilitation phase.

The primary research question for this study was as follows: Are lower-extremity strength-training exercises, plus conventional physiotherapy, more effective than conventional physiotherapy alone in improving the rate of change in gross motor function and walking skills in persons with stroke in an intensive rehabilitation program? Secondary questions included the following: What are the short-term effects on gross motor function, walking, and muscle tone as measured at 4 weeks? Are there adverse effects of strength training in these patients? What is the long-term effectiveness of this treatment, as measured at 6 months after discharge?

METHODS

Participants

Our target population was patients who receive intensive physical therapy in conjunction with other team therapies for rehabilitation after stroke. The goals of rehabilitation in this population are to maximize the patients' independence and to minimize the burden of care on their families and society by helping them to achieve a level of functioning that requires a minimum of subsequent professional and private care. Patients admitted to the stroke programs at 5 teaching hospitals in Hamilton and Toronto, ON, Canada, were assessed to determine whether they met eligibility criteria. This study was approved by the ethics committees of each clinical site. Sampling was performed by assessing consecutive admissions to the stroke programs.

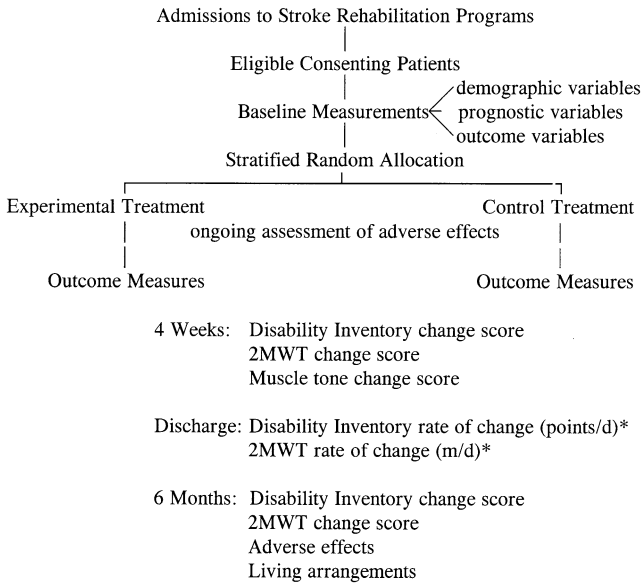

Fig 1. Overview of the design. 2MWT, 2-minute walk test; * Primary outcome measures.

Treatment involved both the leg and foot and required that motor control be at stage 3, 4, or 5 on the Chedoke-McMaster Stroke Assessment (CMSA) instrument before strengthening exercises were begun. Patients who were at stage 2 foot were included. Previous data from 1 of the sites showed that patients at stage 2 in recovery of foot function represented 37% of the eligible group and that, of those, 44% improved to stage 3. Groups were balanced according to the stage of recovery of the foot by using it as a stratification factor for allocation. Patients with a score of greater than 90 on the CMSA Disability Inventory (a measure of gross motor skills on a scale of 14 to 100) were excluded to maintain homogeneity and to minimize a ceiling effect.

The inclusion criteria were as follows: (1) less than 6 months after stroke; (2) able to understand and follow instructions; (3) motor recovery of the leg at stage 3, 4, or 5, as defined by the CMSA stages; (4) motor recovery of the foot at stage 2, 3, 4, 5, or 6; and (5) informed consent given by the participant or a substitute decision-maker.

The exclusion criteria were as follows: (1) CMSA Disability Inventory score greater than 90 points, (2) active arthritis, (3) joint or muscular problems affecting the lower extremities, (4) history of spinal fracture due to osteoporosis or any condition that would prevent a patient from performing strengthening exercises, and (5) uncontrolled hypertension or cardiac condition as determined by the physician.

Study Design

The study design is presented in figure 1. Patients who consented to participate underwent baseline measurements before their stratified random assignment to either a progressive resistance exercise group or the control group. Outcome measures were taken by a blinded observer at 4 weeks, discharge, and 6 months after admission. Adverse effects were monitored throughout the intervention phase.

Interventions

Experimental group. Progressive resistance exercises were performed with weights at the waist or on the lower extremities. Given the specificity of strength training,[32] the exercises were designed to be performed in functional patterns of movements, with the exception of the ankle exercises. We used an ankle exerciser to which variable weights could be applied in each direction of movement with the patient sitting. Thirty-minute exercise sessions took place 3 times a week and were supervised by kinesiologists and therapy assistants. The treatment group exercise program details are given in appendix 1.

Control group. The control group exercises were the same as for the experimental group (see appendix 1), including the frequency and number of repetitions, except that no external resistance was applied with weights.

All exercises by both groups were documented. Verbal and manual guidance was given if needed to correct the quality of movement. Any muscle soreness from a previous session was documented, and the patient did not resume exercising until the soreness had abated.

The stroke programs provided multidisciplinary treatment. All patients received conventional physical therapy: techniques to facilitate and inhibit impaired movements, balance retraining, motor control exercises, stroke mat classes, gait training, and gross motor skills training. Two centers used a predominantly neurodevelopmental therapy approach, and the others used an eclectic approach. Therapists were instructed not to use weights or other resistance equipment during conventional therapy.

Primary null hypothesis. The difference between the adjusted means for the rate of change of gross motor function and walking would be zero at discharge from the rehabilitation program.

Secondary null hypotheses. At 4 weeks, the differences between the adjusted means for change in gross motor function, walking, and muscle tone would be zero. At discharge, the experimental and control groups would have the same incidence of adverse effects. At 6 months, the differences between the adjusted means for gross motor function and walking would be zero. There would be no difference between the groups in place of residence at 6 months.

Outcome Measurement

The outcomes are outlined in figure 1. For gross motor function and walking, we used the CMSA Disability Inventory.[33] Content validity, test-retest reliability (intraclass correlation coefficient [ICC], $>.80$), construct longitudinal validity, and responsiveness have been demonstrated for this inventory.[33] It has 10 items in the Gross Motor Function Index and 5 items in the Walking Index. Items are scored on a 1- to 7-point ordinal scale that is related to the amount of assistance required to perform the item. Higher scores indicate better function.

Walking velocity was measured with the 2-minute walk test[34] (2MWT). Patients were instructed to walk as far as possible in 2 minutes without compromising their safety. The test was standardized so that no encouragement was offered. An earlier validation study at Chedoke-McMaster Hospitals had found the 2MWT's interrater reliability to have an ICC of .92 and a standard error of measurement of 7.0m.

The number of days a patient was in the program was counted. If a patient reached his/her discharge status but remained hospitalized while waiting for equipment or home renovation needs, measurements were taken at the time rehabilitation goals were achieved.

Adverse effects were assessed at each visit before the exercises were started. Patients were asked if they had any problems with pain or stiffness after the last session and whether they had any other problems related to the exercises.

Muscle tone was measured with the Modified Ashworth Scale[35] (MAS). This 6-point scale scores the amount of muscle tone felt by the examiner in response to a 1-second passive movement at the joint. Sloan et al[36] tested interrater reliability for assessing knee flexion, and the Spearman correlation coefficient was .62. Because .62 is a low correlation coefficient, we used a mean of 3 measures.

Discharge living arrangements were scored as follows: acute facility, 1; rehabilitation facility, 2; long-term care, 3; retirement home, home for the aged, or transitional living residence, 4; senior's apartment or relative's residence, 5; home, 6; or death, D.

To assess the balance between the 2 groups on potential confounders, we assessed the variables that had evidence of prognostic importance for the primary outcomes in patients at this stage of rehabilitation.[37-39] The following were measured at baseline: age, sex, previous stroke, time since onset of stroke, stage of recovery of the arm and leg, CMSA Disability Inventory score, and the FIM™ instrument score. Visual inattention was assessed per the method of Barer.[39] Stroke type (lacunar vs nonlacunar) was determined based on the patient's computed tomography scan report.

Sample Size

Sample size was based on calculations for both primary outcomes. A minimum clinically important effect of .10 points per day (a mean of a 7-point change) for the Disability Inventory and .27m/d (mean change, 19m) for the 2MWT were determined based on the CMSA validation study[33] and on a pilot study (JD Moreland, unpublished data, 1993) of progressive resistance training in patients with chronic stroke. Data from a previous sample from 1 site were used to estimate the standard deviation (SD) and lower bound of the 90% confidence interval (CI) of the correlation coefficient for the major covariate (admission Disability Inventory). Using an adjustment for the major covariate, an α of .025 (1 sided) and a β of .20, the sample size was calculated to be 64 for gross motor function and 120 for the 2MWT. Using the 2MWT sample size and allowing for a 10% dropout rate, 134 patients were needed.

Randomization

Generation of the random allocation sequence was performed by a biostatistician, who used blocks of size 2 or 4 in each stratum and an allocation ratio of 1 to 1 by using S-PLUS, version 5,[a] to generate the random numbers. Stratification was performed for the major potential confounder, admission Disability Inventory (<30 or ≥ 30 points), and for the stage of recovery of the foot (stage <3 or ≥ 3), yielding 4 strata. Once an individual agreed to participate, the site co-investigator determined the patient's stratum and telephoned a central office, where the research secretary documented the assignment. The site coordinator then informed the intervention kinesiologists/therapy assistants of the patient and his/her assigned group. Group assignment was not disclosed to the members of the stroke rehabilitation teams.

Blinding

Outcome measurements were taken by 2 blinded research assistants: 1 in Toronto and 1 in Hamilton. Their usual activ-

Table 1: Sample Demographic and Clinical Information

Variable	Progressive Resistance (n=68)	Control (n=65)
Age (y)	69.1±14.8	72.0±12.1
Sex		
Male	39 (57%)	42 (65%)
Female	29 (43%)	23 (35%)
Stroke type		
Nonlacunar	36 (53%)	36 (55%)
Hemiplegic side		
Left	27 (40%)	31 (48%)
Right	35 (51%)	27 (41%)
Bilateral	5 (7%)	6 (9%)
Missing	1	1
Complications		
Skin breakdown	4 (6%)	4 (6%)
Deep vein thrombosis	7 (10%)	4 (9%)
Hemianopsia	1 (1%)	1 (2%)
Seizures	4 (6%)	3 (5%)
Comorbidities		
Hypertension	42 (62%)	39 (60%)
Diabetes	20 (29%)	20 (31%)
Orthopedic	12 (18%)	17 (26%)
Smoking	13 (19%)	8 (12%)
Other	48 (71%)	43 (66%)
Previous stroke	10 (15%)	22 (34%)
CMSA stage of leg	3.9±0.9	3.8±0.9
CMSA stage of arm	3.0±1.5	3.1±1.3
Visual Inattention Test score		
1	47 (69%)	39 (60%)
2	8 (12%)	11 (17%)
3	8 (12%)	4 (6%)
Missing	2	11
Days from stroke to admission	36.8±27.8	38.1±25.6
Baseline CMSA Disability Inventory	47.2±14.6	50.5±14.7
FIM	72.6±21.9	76.3±21.9

NOTE. Values are mean ± SD or n (%).

ities were not near the training areas, and the importance of maintaining blinding was emphasized to them. To ensure that conventional therapy was similar between the groups, attempts were made to keep the physical therapists who gave the conventional therapy blinded. Therapists and patients were instructed not to discuss their study treatment, and the study exercises were performed in an area separate from the conventional therapy area.

Statistical Analyses

Primary questions. SAS, version 6.12,[b] was used for analyses. The rate of change was calculated by dividing the change in score on the CMSA Disability Inventory and the change in meters on the 2MWT by the number of days the patient was in the rehabilitation program. Analysis of covariance (ANCOVA) was performed for each outcome. The level of significance was set at .025 because there were 2 primary outcome measures. Tests were 1 sided because the experimental treatment would not be used unless it was found to be superior to conventional treatment. The covariates were the 2 stratification variables, site, and the prognostic variables that were measured at baseline, as described above.

Secondary questions. ANCOVA was performed to test change scores for gross motor function and the 2MWT at 4 weeks and 6 months. A Mann-Whitney *U* test was performed for the MAS change scores at 4 weeks, and a chi-square test was performed for living arrangements at 6-month follow-up. Adverse effects were analyzed dichotomously with the chi-square test and by the Mann-Whitney *U* test for the percentage of sessions reporting adverse effects.

RESULTS

The recruitment period was September 1996 to July 1998, with follow-up completed in January 1999. Thirty-six percent of the admitted patients were eligible for the study. There were 133 subjects who completed the baseline assessments and were randomized. The baseline demographic and clinical characteristics of each group are given in table 1. More control subjects than experimental subjects had had a previous stroke. The flow of patients through each stage of the study is shown in figure 2. The follow-up at 4 weeks was 93%, at discharge 89%, and at 6 months 80%. All subjects were approximately equally likely to drop out. At discharge, which was the primary endpoint, the control dropouts tended to be older and had lower Disability Inventory scores, but at 6 months both the control and experimental dropouts had similar demographic and clinical characteristics.

After the study, we questioned the evaluators about the blinding, and they reported that there were no instances of unmasking. We were also interested in whether the clinical staff who provided conventional therapy became knowledgeable about group assignments. Physical therapists said that they became knowledgeable about the group assignment of 8 subjects: 7 in the experimental group and 1 in the control group.

The analysis was performed by intention to treat. There were 3 subjects, all in the experimental group, for whom we were unable to collect data at any of the 3 follow-up times. They did not attend any of the exercise sessions.

The median length of stay in the experimental group was 62 days, and in the control group it was 56 days (Mann-Whitney *U* test, $P=.21$). Attendance at exercise sessions was a mean ± SD of 15.2±9.5 for the experimental group and 16.9±10.6 for the control group ($P=.36$). The percentage of scheduled study treatments attended was 79%±17% for the experimental group and 85%±12% for the control group ($P=.02$). The weights lifted at the beginning and end of the exercise program for the experimental group are reported in table 2. The average changes varied from 1.0 to 2.1kg, and all changes were statistically significant.

The unadjusted results for the primary outcomes are reported in table 3. The adjusted analyses (table 4) did not show any statistically significant differences. No clinically important differences were noted for the Disability Inventory; however, for the 2MWT, the differences between the experimental and control groups may be clinically important in favor of the control group, because its subjects experienced larger gains. The study's power to detect the largest difference in the 2MWT (5m at 6mo) was extremely low, at approximately 7%.

Subgroup analyses were not postulated a priori; however, we thought it would be interesting to study subjects who were most similar to frail older adults. In studies of that population, randomized controlled trials (RCTs) have been consistent in showing improved mobility as a result of muscle strengthening programs.[40-42] A subgroup of our participants who were 65 years of age or older and had reached at least stage 4 motor recovery of the leg were examined. In this subgroup, there were no clinically important or statistically significant differences at 4 weeks or at discharge. At 6-month follow-up, the control group remained the same for both the CMSA Disability Inventory and the 2MWT,

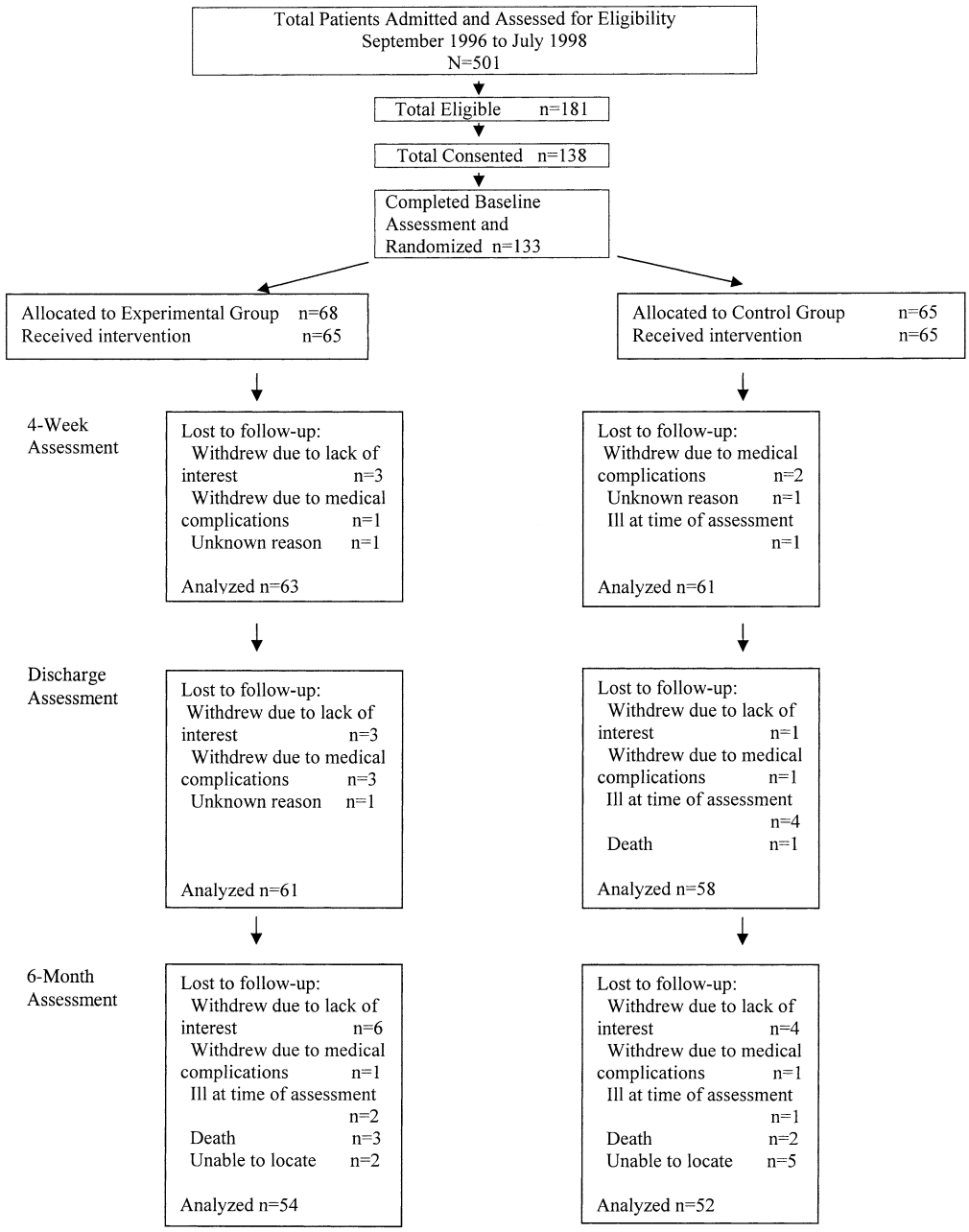

Fig 2. Flow of participants through each stage of the trial.

Table 2: Weights During Experimental Exercises

Variable (kg)	Baseline	Discharge	Mean Change	*P*
Hip abductors	1.5±1.2	3.4±2.7	1.9	.00
Hip flexors	1.4±1.1	3.0±2.3	1.7	.00
Hip extensors	1.3±1.1	2.7±2.2	1.5	.00
Knee bends	0.3±0.7	1.2±1.7	0.9	.00
Sit to stand	0.4±0.7	1.5±1.8	1.1	.00
Ankle plantarflexors	3.2±2.7	7.9±6.4	4.7	.00
Ankle dorsiflexors	2.5±2.2	5.0±4.4	2.5	.00
Ankle evertors	1.5±1.4	3.6±3.0	2.1	.00
Ankle invertors	1.3±1.4	3.4±3.0	2.1	.00

NOTE. Values are mean ± SD.

whereas the experimental group continued to improve by 8 points on the Disability Inventory and by 16m on the walk test. The adjusted analysis at 6 months was statistically significant ($P=.02$) for the Disability Inventory.

Another subgroup analysis of leg recovery equal to stage 3 showed that the control group consistently did better on the main outcome measures. There were no statistically significant differences; however, the change from baseline to 6-month follow-up for the walk test showed a large difference between the groups, with the experimental group changing by 15m and the control group by 26m.

Living arrangements at 6-month follow-up were similar for both groups (χ^2, $P=.93$). Seventy-two percent of the experimental group lived at home, whereas 71% of the control group did. There were 3 deaths in each group.

Table 3: Unadjusted Results for Primary Outcomes

Variable	Baseline	4wk	Discharge	6mo
Disability Inventory (points)				
Experimental	50.88±13.48	60.17±15.08	63.92±16.90	69.85±20.52
Control	52.68±12.98	61.95±17.09	65.53±17.27	70.56±21.30
2MWT (m)				
Experimental	29.74±27.64	41.19±40.37	46.63±38.20	58.57±52.74
Control	30.88±27.96	45.35±38.76	51.72±41.35	63.18±49.07

NOTE. Values are mean ± SD.

Adverse effects were analyzed in 2 ways. They were dichotomized into any or none and were divided into pain/stiffness or other (table 5). We also analyzed the percentage of sessions in which adverse effects were reported (table 6). Although there were more adverse occurrences in the experimental group, none persisted, there were no withdrawals from the trial, and the differences were not statistically significant. At the 6-month follow-up, no adverse effects were identified.

Testing with the MAS for muscle tone showed both groups to have low scores. Mean scores for the groups were less than 1.0 (less than a slight increase in muscle tone), and at 4 weeks and discharge, the scores were slightly higher in the control group, although there were no statistically significant differences.

DISCUSSION

Our results indicate that blinding of the outcome evaluators was successful. There was a potential in 8 instances for bias leading to co-intervention to occur when the clinical staff became aware of a patient's group assignment. It is difficult to predict in which direction this bias would have operated, because therapists differed in their beliefs about the appropriateness of strengthening exercises for stroke patients.

Although muscle strength increased in response to resistance exercises in patients with stroke in other studies,[25-27] we did not find a functional advantage to progressive resistance exercises of the lower extremities. Because pilot testing had shown that we were unable to measure training-specific muscle strength in a reliable way, we did not measure it directly. It is possible that muscle strength did not improve in the experimental group or that it improved to the same extent in both groups. Consideration must be given to our parameters of training. Because we were unable to reliably measure a 1 repetition maximum for the training movements, resistance was increased based on perceived exertion. Moderate exertion was used as the criterion for practical reasons—to avoid discomfort and subsequent withdrawal from the study and to avoid fatigue in patients who usually had a full day program of therapy. Two sets of 10 repetitions 3 times a week are well accepted as being effective for strengthening.[43] Studies of individuals with stroke have shown significant increases in strength after 1 month of training[24] and 6 weeks of training.[25,26] In our study, the mean number of weeks of training was 6.6 (range, 0.3–20.3wk) for the experimental group and 6.9 (range, 1.3–27.0wk) for the control group. Hence, we think that an adequate stimulus was provided to result in muscle strengthening. Our study results are consistent with those of other studies in showing that an increase in muscle tone does not occur secondary to resistance training.

It is possible that our outcome measures were not adequate to detect a difference between the groups. Outcomes in other studies that detected pre- and posttraining differences were symmetry in weight bearing when standing from sitting[25] and repeated chair stand time.[27] We did not assess unilateral standing balance on the hemiparetic side. In a pilot study of individuals with stroke for 6 months or longer who were using free weights in a progressive lower-extremity weight training program for 10 weeks, we found no change in unilateral balance. Weiss et al[27] also found no change in unilateral leg stance over a 12-week program of resistance training in their sample.

For our subjects, the experimental and control conditions were imposed in addition to the conventional therapy. The additional physical work may have caused fatigue, which could have negated any positive effects. It is possible that strength training incorporated into a program of regular therapy may be effective. A trial in which 1 component of conventional therapy is removed (eg, stroke exercise class) and strength training is substituted would help determine whether this is true.

None of the previous studies of resistance training in stroke patients had a control group in which the same exercises were given without the resistance. The geriatric literature reports numerous RCTs of resistance training and most of these studies used an attention intervention for the control group or provided no intervention at all. One exception[44] in these studies compared exercises in patients using .68-kg wrist weights with the same exercises without the use of wrist weights. There were no statistically significant differences between the 2 groups for fitness, strength, flexibility, balance, or mood. This is not

Table 4: Adjusted Results and Effect Sizes for Primary Outcomes

Variable	4wk	Discharge	6mo
Disability Inventory	n=119	n=115	n=101
Experimental	15.78 points	.27 points/d	22.47 points
Control	14.46	.29	21.80
Effect size (95% CI)	1.32 (−2.68 to 5.31)	−.02 (−.10 to .06)	.67 (−5.29 to 6.65)
2MWT	n=124	n=114	n=100
Experimental	−2.62m	−.01m/d	10.26m
Control	5.01	.15	15.91
Effect size (95% CI)	−7.62 (−18.65 to 3.40)	−.16 (−.37 to .05)	−5.65 (−21.33 to 10.02)

surprising, given the small amount of weight that was used. Future studies need to clarify whether it is the progressive resistance or the movement practice that is responsible for the improvements in function in frail older adults.

Our subgroup analyses suggest that poststroke patients who are most similar to frail older adults may experience long-term benefits of strength training. Further research with patients who are stage 4 in leg recovery is needed to confirm our findings. It may also be of benefit for such studies to measure other outcomes, such as level of daily physical activity after discharge and incidence of falls. Although there was a tendency for those in the experimental group to continue with a regular exercise program after discharge (37 of 52 experimental vs 30 of 51 control), the difference was not statistically significant ($P=.19$). The other subgroup analysis suggests that patients with more severe stroke, as defined by motor recovery of the leg at less than stage 4, may be detrimentally affected by a strengthening program. Given the consistently poor response of subjects with leg recovery at stage 3, we would recommend that progressive resistance exercises not be prescribed for this population.

Although studies indicate that muscle strengthening is specific to the movements that are trained,[32] placebo-controlled studies that use isokinetic and standard weight station training would be of interest, given the results of previous studies that used these methods. In particular, the leg press exercise described by Inaba et al[24] looks promising.

CONCLUSION

Progressive resistance exercise, as applied in our study, versus the same exercises without added resistance, did not affect common clinical measures of gross motor function and walking in stroke patients undergoing inpatient rehabilitation. As reported by other studies, there were no detrimental effects on muscle tone from resistance training.

APPENDIX 1: EXPERIMENTAL EXERCISE PROGRAM

For exercises 1–5, an ankle foot orthosis is worn if necessary.

1. Standing with support, weight at unaffected ankle, step forward and back with unaffected lower extremity. Hip-hiking is permitted. Target muscles are affected hip abductors with cocontraction of adductors for stabilization of the pelvis. Target function is gait.
2. Standing with support, affected foot 1ft behind unaffected foot, weight at affected ankle, step forward to a 1-ft length in front of unaffected foot. Target muscles are affected hip flexors, hamstrings (initial swing), and quadriceps (terminal swing). Target function is gait.
3. Standing with support, affected foot 1ft in front of unaffected foot, resistance at affected ankle, pull affected low extremity straight back to a 1-ft length behind unaffected foot. Target muscles are hip extensors and cocontraction of hamstrings and quadriceps (stance phase). Target function is gait.
4. Standing with support, return to stance unaffected foot raised from floor (ie, standing on affected foot only), and bend affected knee to 45° position. Weight at waist. (Unilateral knee bend.) Target muscles are the quadriceps, plantarflexors, and hamstrings (hip extension). Target functions are stair climbing, sit to stand, and push-off phase of walking. The control group performed this exercise with both lower extremities simultaneously (ie, unaffected foot on the floor, bilateral knee bend).
5. Sit to stand. Feet positioned in line with chair front legs. Deviation to the side is not permitted. Weight at waist. Document chair height. Target muscles are quadriceps, and target functions are sit-to-stand and floor-to-stand transfers. If patient is unable to come to standing, progress by changing the height of the chair before adding weights.
6. Ankle plantarflexion in sitting with ankle exerciser with stabilization of the femur by the instructor and weights on the posterior post of the exerciser.
7. Ankle dorsiflexion in sitting with ankle exerciser with stabilization of the femur by the instructor and weights on the anterior post of the exerciser.
8. Ankle eversion in sitting with ankle exerciser with stabilization of the femur by the instructor and weights on the lateral post of the exerciser.
9. If ankle eversion is present, ankle inversion in sitting with ankle exerciser with stabilization of the femur by the instructor and weights on the medial side of the exerciser.

Patients were seen individually. All exercises were started with a 2.25-kg (5-lb) weight. Two sets of 10 repetitions were performed. The resistance was increased based on patient perception of effort. After the second set of each exercise, patients were asked whether they found the exercise easy, moderate, or hard. If a patient reported the exercise to be easy, the weight for the exercise was increased by approximately 1.1kg—more if the exercise appeared to be very easy for the subject. If the exercise was reported to be hard, the weight was decreased, and if it was perceived to be moderate, the weight was not changed.

Table 5: Dichotomized Adverse Effects

Variable	Pain or Stiffness		Other Adverse Effects	
	No	Yes	No	Yes
Experimental	54	14	60	8
Control	57	8	62	3
Significance	χ^2, $P=.20$		Fisher exact test, $P=.21$	

Table 6: Percentage of Sessions Reporting an Adverse Effect

Variable	Pain or Stiffness		Other Adverse Effects	
	Mean	Median	Mean	Median
Experimental	4.44	0	2.72	0
Control	1.63	0	0.83	0
Statistical significance	Mann-Whitney U test, $P=.16$		Mann-Whitney U test, $P=.11$	

References

1. Petrasovits A, Nair C. Epidemiology of stroke in Canada. Health Rep 1994;6:39-44. Comment in: Health Rep 1994;6:9-12.
2. Hodgson C. Prevalence and disabilities of community-living seniors who report the effects of stroke. Can Med Assoc J 1998; 159(6 Suppl):S9-14.
3. Borbonnais D, Vanden Noven S. Weakness in patients with hemiparesis. Am J Occup Ther 1989;43:313-9.
4. Giuliani CA. Dorsal rhizotomy for children with cerebral palsy: support for concepts of motor control. Phys Ther 1991;71:248-59.
5. Hammond MC, Fitts SS, Kraft GH, Nutter PB, Trotter MJ. Cocontraction in the hemiparetic forearm: quantitative EMG evaluation. Arch Phys Med Rehabil 1988;69:348-51.

6. Knuttson E, Martensson A. Dynamic motor capacity in spastic paresis and its relation to prime mover dysfunction, spastic reflexes and antagonist co-activation. Scand J Rehabil Med 1980; 12:93-106.
7. Gowland C, de Bruin H, Basmajian JV, Plews N, Burcea I. Agonist and antagonist activity during voluntary upper limb movement in patients with stroke. Phys Ther 1992;72:624-33.
8. Whitley KL, Sahrmann SA, Norton BJ. Patterns of muscle activity in the hemiplegic upper extremity [abstract]. Phys Ther 1982;62: 641.
9. Sahrmann SA, Norton BJ. The relationship of voluntary movement to spasticity in the upper motor neuron syndrome. Ann Neurol 1977;2:460-5.
10. Colebatch JG, Gandevia SC, Spira PJ. Voluntary muscle strength in hemiparesis: distribution of weakness at the elbow. J Neurol Neurosurg Psychiatry 1986;49:1019-24.
11. Di Fabio RP. Lower extremity antagonist muscle response following standing perturbation in subjects with cerebrovascular disease. Brain Res 1987;406:43-51.
12. Andrews AW, Bohannon RW. Distribution of muscle strength impairments following stroke. Clin Rehabil 2000;14:79-87.
13. Bohannon RW, Walsh S. Nature, reliability, and predictive value of muscle performance measures in patients with hemiparesis following stroke. Arch Phys Med Rehabil 1992;73:721-5.
14. Bohannon RW. Relationship between paretic knee extension strength, maximal weightbearing, and gait speed in stroke patients [abstract]. Phys Ther 1991;71(Suppl):S58.
15. Bohannon RW, Warren ME, Cogman DA. Motor variables correlated with the hand-to-mouth maneuver in stroke patients. Arch Phys Med Rehabil 1991;72:682-4.
16. Bohannon RW, Andrews AW. Strength of lower limb related to gait velocity and cadence in stroke patients. Physiother Can 1986; 38:204-6.
17. Bohannon RW. Correlation of lower limb strengths and other variables with standing performance in stroke patients. Physiother Can 1989;41:198-202.
18. Nakamura R, Watanabe S, Handa T, Morohashi I. The relationship between walking speed and muscle strength for knee extension in hemiparetic stroke patients: a follow-up study. Tohoku J Exp Med 1988;154:111-3.
19. Wade DT, Hewer RL. Motor loss and swallowing difficulty after stroke: frequency, recovery, and prognosis. Acta Neurol Scand 1987;76:50-4.
20. Bohannon RW. Gait performance of hemiparetic stroke patients: selected variables. Arch Phys Med Rehabil 1987;68:777-81.
21. Bohannon RW. Strength of lower limb related to gait velocity and cadence in stroke patients. Physiother Can 1986;38:204-6.
22. Nakamura R, Hosokawa T, Tsuji I. Relationship of muscle strength for knee extension to walking capacity in patients with spastic hemiparesis. Tohoku J Exp Med 1985;145:335-40.
23. Hamrin E, Eklund G, Hillgren AK. Muscle strength and balance in post-stroke patients. Ups J Med Sci 1982;87:11-26.
24. Inaba M, Edberg E, Montgomery J, Gillis MK. Effectiveness of functional training, active exercise and resistive exercise for patients with hemiplegia. Phys Ther 1973;53:28-30.
25. 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;76:419-25.
26. Sharp SA, Brouwer BJ. Isokinetic strength training of the hemiparetic knee: effects on function and spasticity. Arch Phys Med Rehabil 1997;78:1231-6.
27. 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;79:369-76.
28. van der Lee JH, Wagenaar RC, Lankhorst GJ, Vogelaar TW, Deville WL, Bouter LM. Forced use of the upper extremity in chronic stroke patients: results from a single-blind randomized clinical trial. Stroke 1999;30:2369-75.
29. Duncan P, Richards L, Wallace D, et al. A randomized, controlled pilot study of a home-based exercise program for individuals with mild and moderate stroke. Stroke 1998;29:2055-60.
30. 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;80:1211-8.
31. Rimmer JH, Riley B, Creviston T, Nicola T. Exercise training in a predominantly African-American group of stroke survivors. Med Sci Sports Exerc 2000;32:1990-6.
32. McComas AJ. Skeletal muscle: form and function. Champaign (IL): Human Kinetics; 1996.
33. Gowland C, VanHullenaar S, Torresin W, et al. Chedoke-McMaster Stroke Assessment: development, validation and administration manual. Hamilton (ON): McMaster Univ; 1995.
34. Connelly DM, Stevenson TJ, Vandervoort AA. Between- and within-rater reliability of walking tests in a frail elderly population. Physiother Can 1996;48:47-51.
35. Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth Scale of muscle spasticity. Phys Ther 1987;67:206-7.
36. Sloan RL, Sinclair E, Thompson J, Taylor S, Pentland B. Interrater reliability of the modified Ashworth Scale for spasticity in hemiplegic patients. Int J Rehabil Res 1992;15:158-61.
37. Gowland C. Predicting sensorimotor recovery following stroke rehabilitation. Physiother Can 1984;36:313-20.
38. Olsen TS. Arm and leg paresis as outcome predictors in stroke rehabilitation. Stroke 1990;21:247-51.
39. Barer DH. The influence of visual and tactile inattention on predictions for recovery from acute stroke. Q J Med 1990;74:21-32.
40. Meuleman JR, Brechue WF, Kubilis PS, Lowenthal DT. Exercise training in the debilitated aged: strength and functional outcomes. Arch Phys Med Rehabil 2000;81:312-8.
41. Krebs DE, Jette AM, Assmann SF. Moderate exercise improves gait stability in disabled elders. Arch Phys Med Rehabil 1998;79: 1489-95.
42. Fiatarone MA, O'Neill EF, Doyle N, et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. N Engl J Med 1994;330:1769-75.
43. Feigenbaum MS, Pollock ML. Prescription of resistance training for health and disease. Med Sci Sports Exerc 1999;31:38-45.
44. Engels HJ, Zhu W, Kazmierski JF. Effects of low-impact, moderate-intensity exercise training with and without wrist weights on functional capacities and mood states in older adults. Gerontology 1998;44:239-44.

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