Is Lower Extremity Strength Gain Associated With Improvement in Physical Performance and Disability in Frail, Community-Dwelling Elders?

Julie M. Chandler, PhD, PT, Pamela W. Duncan, PhD, PT, Gary Kochersberger, MD, Stephanie Studenski, MD, MPH

ABSTRACT. Chandler JM, Duncan PW, Kochersberger G, Studenski S. Is lower extremity strength gain associated with improvement in physical performance and disability in frail, community-dwelling elders? Arch Phys Med Rehabil 1998; 79:24-30.

Background: Strength loss is strongly associated with functional decline and is reversible with exercise. The effect of increased strength on function has not been clearly established. The purpose of this study was to determine whether strength gain is associated with improvement in physical performance and disability.

Methods: One hundred functionally impaired community-dwelling men and women (77.6 ± 7.6yrs) were tested at baseline and outcome for lower extremity strength, physical performance, and disability. After random group assignment, exercise participants received strengthening exercises in their homes three times a week for 10 weeks while control subjects continued their normal activities. Using multiple regression techniques, the relationship between strength gain and improvement in physical performance and disability was assessed, controlling for age, depression, and baseline strength.

Results: A significant impact of strength gain on mobility skills ($p = .0009$) was found. The impact of strength gain on chair rise performance was significant in participants who were more impaired ($p = .04$). Strength gain was associated with gain in gait speed ($p = .02$) and in falls efficacy ($p = .05$), but not with other balance, endurance, or disability measures.

Conclusions: Lower extremity strength gain is associated with gains in chair rise performance, gait speed, and in mobility tasks such as gait, transfers, stooping, and stair climbing, but not with improved endurance, balance, or disability. Strength gain is also associated with improvement in confidence in mobility. Factors that may influence the ability of strength gain to affect function are initial level of frailty and specificity of exercise. These results support the idea that strength training is an intervention that can potentially improve physical health status in many frail elders.

FRAILTY HAS BEEN DEFINED as a loss of physiologic reserve that leads to decline in physical performance and functional independence.[1] Frailty becomes more prevalent as age increases but is no longer considered an inevitable consequence of aging. Some aspects of frailty are known to be reversible; strength loss is reversible even in the oldest old. Because strength loss is associated with poor function, falls, and need for services,[2-6] improving strength might improve outcomes.

Strengthening programs for the elderly are effective.[7-10] Wide variation in muscle strength gains may be accounted for by differences in strength measures, intensity of exercise, or relative health of the study populations. The effects of strength training on mobility performance and quality of life are unclear. Studies in healthy elders find little effect,[11] whereas those in frailer samples report changes in walk time and walk distance.[10,12-14] The association between strength and function may be curvilinear[15]; a critical amount of strength is needed for "normal" performance of specific activities. Above this threshold level of strength, further increase will not enhance performance of the task. Below the threshold, there should, theoretically, be a stronger relation between strength change and change in performance.

Though the overwhelming majority of frail elders live in the community, most studies of exercise in frail elders have been in institutions. A targeted in-home intervention, including strengthening in persons with lower extremity weakness, decreased the rate of falls in a high-risk community-dwelling sample.[16] This multifactorial intervention could not examine the specific impact of exercise on falls. No study has specifically examined the impact of strengthening exercise delivered in the home to frail, functionally impaired elders.

We examined the correlation between changes in lower extremity strength and changes in physical performance and disability in a frail community-dwelling population using progressive resistive strength training delivered in the home. We predicted that strength gain would be associated with improvement in physical performance and disability, and that gains would be greater in those initially at a predefined lower level of frailty.

METHODS

Study Design

This is a prospective controlled clinical trial with baseline and postintervention measures of lower extremity strength, physical performance, and disability. The rationale for choosing this study design was to generate a wide range of strength changes to test their relationship to changes in physical performance and

---

From the Epidemiology Department, Merck Research Laboratories, West Point, PA (Dr. Chandler); the Center on Aging (Drs. Duncan, Studenski) and Department of Medicine (Dr. Studenski), University of Kansas Medical Center, Kansas City, KS; the School of Pharmacy, Department of Health Services Administration, University of Kansas, Lawrence, KS (Dr. Duncan); the Department of Veterans Affairs, Canandaigua, NY (Dr. Kochersberger); and the Department of Medicine, University of Rochester, Rochester, NY (Dr. Kochersberger).

Submitted for publication December 17, 1996. Accepted in revised form June 19, 1997.

Supported by a grant (Project R661-RA) from the Department of Veterans Affairs, Rehabilitation Research and Development Service, and the Center for the Study of Aging and Human Development, Claude Pepper Center, Duke University, Durham, NC.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the authors or upon any organization with which the authors are associated.

Reprint requests to Julie Chandler, PhD, Merck Research Laboratories, PO Box 4, BL2-3, West Point, PA 19486-0004.

0003-9993/98/7901-4303$3.00/0

disability. Based on evidence from the literature, we anticipated that the intervention group would have greater gains in strength than the control group.

Study Sample

Fifty men and 50 women, community-dwelling volunteers older than 64 years of age, were recruited from areas within a 25-mile radius of the Durham Veterans Affairs Medical Center (DVAMC). Participants were recruited from outpatient DVAMC clinics, Duke Aging Registry, elderly housing complexes, home health agencies, Meals on Wheels programs, and private clinics in the area. Telephone screening eliminated those not interested, too fit ($\geq$3 on Reuben's Advanced Activities of Daily Living)[17] or diagnosed with: (1) terminal illness ie, the patient was not expected to survive 6 months; (2) severe, unstable cardiac disease, including myocardial infarction in the past 6 months; (3) severe fixed or progressive neurologic disease (eg, stroke with significant hemiplegia, Parkinson's disease); (4) complete blindness; or (5) lower extremity amputation.

Potential participants underwent further review of medical records and a medical screening by a geriatrician. Persons scoring below an 18 on the Folstein Minimental Status Exam[18,19] were excluded if unable to follow a 3-step command. All participants met a prespecified criterion for frailty, defined as the inability to descend stairs step over step without holding the railing. Poor stair descent has been associated with increased risk for falls.[20] We stratified two levels of functioning within our sample, operationally defined as (1) higher functioning, ie, those who were able to rise from a standard 17" chair without using their arms, and (2) lower functioning, ie, those who were unable to rise without using their arms. Each participant's primary physician approved exercise participation.

Of the initial pool of 850 potential subjects contacted, 178 were excluded for medical reasons, 241 were too fit, 202 were not interested, and 129 were excluded for other reasons (eg, lived in rest home, or not able to commit for 3-month study duration). One hundred individuals met eligibility criteria and agreed to participate.

Protocol

After informed consent, subjects underwent baseline testing of strength, physical performance, and disability. Subjects were then block-randomized and stratified by the two levels of functioning.

The exercise intervention was initiated within 5 days of baseline testing. Exercise subjects were supervised by a physical therapist in a 10-week, 3-session-per-week, in-home program of resistive lower extremity exercises using theraband and body weight for resistance (appendix A). Using principles of progressive resistive exercise, theraband resistance for each participant was systematically increased during the 10-week program. Exercises included resisted hip extension and abduction, knee flexion and extension, ankle dorsiflexion, toe raises, chair rises, and stair stepping. The control subjects were asked not to initiate any new exercise program during the 10-week period.

Within 5 days of the end of the intervention/control period, all subjects were retested in the laboratory for posttest measures of strength, physical performance, and disability. Control subjects were then offered the exercise program.

Testing Procedures

All baseline laboratory testing was performed by persons blinded to the subject's intervention status. The examiner who performed postintervention testing was, by protocol design, not familiar with participant and had no knowledge of the participant's baseline scores. Testing took approximately 2.5 to 3 hours to complete. Participants were allowed to rest as needed. Participants were offered a lunch break in the hospital cafeteria when the testing session ran into the lunch hour.

Lower extremity strength testing. Strength of bilateral knee extensor and flexors, ankle dorsiflexors, and plantarflexors was measured isokinetically and isometrically using the Cybex 6000 isokinetic dynamometer.[a] Knees were tested at 60°/sec and ankles at 30°/sec. Participants were seated comfortably on the Cybex chair apparatus with hips and knees flexed at approximately 90°. The trunk, pelvis, and distal thigh of the tested extremity were stabilized with Velcro straps. For the knee measures, the axis of rotation of the dynamometer aligned with the knee joint axis. Peak torque in N-m and work produced during each of the last three of five repetitions were recorded and averaged. Isometric peak torque produced by the knee flexors and extensors was measured by setting the dynamometer speed to 0°/sec and positioning the limb at 60° flexion for knee extensor strength and 30° flexion for knee flexor strength. Two 5-second contractions in each direction (flexion and extension) were recorded and averaged.

For the ankle, peak torque and work produced during each of the last three of five repetitions were recorded and averaged. With the knee joint positioned in 45° flexion, isometric ankle dorsiflexion and plantar flexion were measured by positioning the ankle joint in 10° plantar flexion for plantar flexion strength and in 25° plantar flexion for dorsiflexion strength. The peak torque generated during each of two 5-second contractions was recorded and a mean of the two trials was calculated.

Isometric hip abductor strength was measured using the Nicholas hand-held dynamometer[b] with the participant supine and the hip joint in 30° abduction and 0° flexion. It was determined in preparatory pilot work before the start of this study that better stability, patient comfort, and, hence, reproducibility could be achieved by testing the hip abductors in the supine position than in the sidelying position in this frail population. The patient was positioned supine with straps securing the pelvis and distal thigh of the tested extremity. The point of application of the dynamomter pad was approximately 1 inch proximal to the lateral malleolus in most participants. If the participant experienced discomfort at that point of application, the dynamometer was adjusted proximally until there was no discomfort. The lever arm (distance from the greater trochanter to the point of application of the dynamomter pad) was recorded bilaterally. The participant pushed against the dynamometer as the tester pushed in the direction of adduction. An assistant helped stabilize the participant by placing a hand at the pelvis and distal thigh of the untested extremity and preventing movement of the participant's body as he or she pushed outward with the tested leg. The peak force generated (in Newtons) was recorded digitally. Participants were given two submaximal warm-ups and three maximal test trials. The mean peak torque of the three test trials was calculated for each side.

Choosing the best strength measures. Different muscle groups are used for different functional tasks. The association between strength gain and function must be studied based on kinesiologic principles in the context of specific muscle-function relationships. In preparation for the current study, we developed and tested summary measures of strength (from the muscle groups tested above), for each performance and disability measure using cross-sectional data (table 1).[21] The strength measure with the best conceptual and evidence-based association with each specific performance or disability measure is used in the current analyses. The derived summary measures were calculated using the method described in appendix B.

Table 1: Strength Indexes for Performance and Disability Measures

	Strength Index	Muscles Used
Mobility Skills	Knee extensor, plantar flexor isokinetic peak torque index	Bilateral knee extensor, plantar flexors
Chair Rise	Bilateral knee extensor isokinetic peak torque index	Bilateral knee extensors
Functional Reach	Distal isokinetic peak torque index	Bilateral dorsiflexors and plantar flexors
Static Sway	Distal isometric peak torque index	Bilateral dorsiflexors and plantar flexors
Gait Speed	Bilateral knee extensor, plantar flexor isokinetic work index	Bilateral knee extensors, plantar flexors
6-Minute Walk	Bilateral knee extensor, plantar flexor isokinetic work index	Bilateral knee extensors, plantar flexors
Falls Efficacy Scale	Total isokinetic peak torque index	Bilateral knee extensor and flexors and dorsiflexors, plantar flexors
MOS-36 (physical scale)	Total isokinetic work index	Bilateral knee extensor and flexors and dorsiflexors, plantar flexors

Physical performance measures. The following characteristics of balance, walking, mobility, and chair rise were measured.

Balance. Functional reach was defined as the maximum distance a subject could reach forward beyond arm's length while maintaining a fixed base of support in the standing position and was recorded as the mean of the last three of five trials.[22] *Spontaneous postural sway* was recorded as the participant stood, eyes closed, with the medial malleoli approximately 2.5cm apart, on a 61cm × 61cm force platform constructed by the Biomedical Engineering Department at Duke University. Details of the force platform construction and data acquisition software have been described previously.[3] The maximum excursion of the center of pressure in the medial-lateral direction during each of two 30-second trials was recorded and averaged. Center of pressure was recorded at 50Hz.

The *falls efficacy scale* assessed confidence in a subject's ability to avoid a fall during each of 10 essential, nonhazardous activities of daily living.[23] This instrument was added midway in the study and administered to approximately 70 participants.

Walking. Endurance was assessed using the 6-minute walk test.[24,25] The distance (in feet) walked at a normal pace on a measured walkway in 6 minutes was recorded. Participants were instructed to walk as far as possible during the 6 minutes and were given standardized encouragement.[26] *Gait speed* used two trials of a timed 10-meter walk at comfortable walking speed, which were then averaged. *Speed* was calculated in meters per second.

Mobility. The *mobility skills protocol* was used to assess a series of 13 progressively challenging mobility skills, including sitting balance, sitting reach, transfer, rising from a chair, standing balance, picking up an object from the floor, walking, turning, stopping suddenly, stepping over a shoe box, reaching, and ascending and descending stairs.[27] The mobility skills protocol has been validated in elderly populations from community-dwelling frail to nursing home elderly.[20,28]

Chair rise. The participant was asked to rise from a series of 6 randomly ordered seat heights ranging from 13″ to 23″. The subject's inability to rise from a chair without using his or her arms constituted a failure. The chair rise score was the lowest height from which the subject could successfully rise.

Disability measure. *Medical Outcomes Study (36-item short form) health survey (MOS-36)* was administered in full,[29] but only the physical functioning subscale (question 3) was used as the outcome measure in this study. The MOS-36 was self-administered except in cases of poor vision or low literacy, in which case it was administered by interviewer. The pretest to posttest mode of administration remained the same for each individual.

Depression scale. A short, 11-item depression scale adapted and validated by Koenig and colleagues[30] was used to obtain a clinical marker of depression. The measure was self-administered except in cases of poor vision or low literacy when it was administered by interview.

Analysis

All data were analyzed using SAS statistical software.[c] Univariate procedures were used to check for normal distribution of each variable. Dichotomous variables were created when the assumption of normality was not met. Only depression and change in chair rise performance were not normally distributed. In those two cases, dichotomous variables were created as follows: depression = yes if >3, gain in chair rise ability = yes if ≥ 1.

To examine the impact of the intervention on strength and performance, we used two-sample, paired t tests to compare change scores between intervention and control participants. For select analyses, we stratified by our two levels of frailty.

Linear regression was used to examine the impact of change in strength (Time 2 − Time 1) on physical performance and disability at Time 2 for all continuous dependent variables. Control variables included age, depression, baseline strength, and baseline performance or disability score. To test for effect modification by level of frailty, models were run separately for

Table 2: Demographics of Study Sample

		Quantiles				
	Mean (SD) or %	0% (Minimum)	25%	50% (Median)	75%	100% (Maximum)
Age	77.6yrs (7.6)	66	71	77	83	97
Education	10.3yrs (4.2)	3	7	11	12.5	20
Depression (Koenig[29])	2.2 (2.3)	0	5	1	3.5	9
Cognition—MMSE	24.3 (4.1)	11	22	25	27	30
Married	45%					
Widowed	43%					
Race	66% white 34% black					
Level of frailty						
Cannot do stairs, can do chair rise	57%					
Cannot do stairs, cannot do chair rise	43%					

Abbreviation: MMSE, Mini–Mental Status Exam.

Table 3: Mean Baseline Values of Physical Performance and Disability for the Total Sample

Performance Task	*n*	Mean (SD)	Range
Mobility skills (0-26)	100	20.6 (3.7)	6-24
Chair rise*	99	4.2 (1.8)	0-6
Functional reach (inches)	100	9.4 (3.0)	0.7-16.3
Spontaneous sway (cm)	80	2.7 (1.3)	0.7-6.6
Gait speed (m/sec)	98	.78 (.25)	.16-1.28
6-Minute walk distance (feet)	100	762.7 (308)	75-1,304
Falls efficacy scale (0-100)	70	77.6 (19.6)	19-100
MOS-36 (physical, q.3)	96	42.4 (23.2)	0-95

* Chair rise score indicates the number of chair heights from which the subject could successfully rise without using the arms. There were six randomly ordered chair heights ranging from 13 to 23 inches. A score of 6 is the highest, indicating success at all heights tested.

each frailty group. If no effect modification was found, the strata were collapsed and the models were re-run, adding frailty level to the other control variables. Logistic regression was applied for the dichotomous outcome, gain in chair rise ability. As in the case of the linear models, a stratified analysis was performed first.

RESULTS

Demographics

Fifty men and 50 women had a mean age of 77.6 years and a mean education of 10.3 years (table 2). Fifty-seven percent were higher functioning according to our level of frailty classification.

Baseline values demonstrate a moderately limited population (table 3). There were no significant gender differences in any variable except chair rise, which was worse in women (*p* = .04). Originally attributed to gender differences in height, chair rise remained significantly different (*p* = .051) by gender even after controlling for height.

Baseline comparability in demographic, strength, performance, and disability data between intervention and control groups is shown in table 4.

Comparison of Change Scores: Intervention Versus Control Subjects

Thirteen (7 controls, 6 exercise) of the 100 dropped out before completing the study. Drop-outs did not differ from participants in any baseline factors. Reasons for drop-outs included illness (*n* = 9), death from pneumonia (*n* = 1), loss of interest (*n* = 1), increased hip pain (*n* = 1), and unwillingness to undergo posttest strength testing (*n* = 1). Analysis of change scores included the remaining 87 participants.

Table 4: Baseline Comparability of Demographic, Strength, Physical Performance, and Disability Measures

	Intervention (*n* = 50)	Control (*n* = 50)
Age (yrs)	77.5 (7.1)	77.7 (7.8)
Cognition (MMSE)	24.5 (4.1)	24.7 (4.1)
Depression (0-11)	2.3 (2.2)	2.1 (2.4)
Mobility skills (0-26)	20.7 (3.0)	20.5 (4.3)
Chair rise (0-6)	4.1 (0.7)	4.3 (1.8)
Gait speed (m/sec)	.78 (.23)	.78 (.28)
6-Minute walk (feet)	783 (283)	743 (332)
Functional reach (inches)	9.3 (2.8)	9.4 (3.3)
Spontaneous sway (cm)	2.9 (1.25)	2.5 (1.3)
Falls efficacy scale (0-100)	78.3 (18)	76.9 (21)
SF36-physical (question 3) (0-100)	40.1 (20.4)	44.8 (25.8)
Representative Muscle Groups:		
Knee extension (right) (N-m)	58.8 (27)	49 (23)
Knee flexion (right) (N-m)	28.7 (18.2)	24.0 (11)
Plantar flexion (right) (N-m)	22.8 (11.6)	20.9 (10.2)
Dorsiflexion (right) (N-m)	9.2 (4.7)	8.5 (4.3)

Values listed as mean (SD); *p* values (α = .05) not significant for any of the variables.

Table 5: Change in Strength: Intervention Versus Control

	Intervention: Mean Change in N-m (SD)	Control Group: Mean Change in N-m (SD)	*p* Value
Right knee extension	+4.9 (14)	−.7 (8.2)	.03
Right knee flexion	+4.6 (7.1)	+.3 (4.8)	.001
Right dorsiflexion	+.81 (3.1)	−.3 (2.1)	.06
Right plantar flexion	+3.1 (6.4)	+.25 (5.7)	.03

Mean strength changes (in N-m) in representative muscle groups presented in this table represent approximately 9% to 16% strength gain for the exercise group and approximately a 1% gain to 3% decline in strength for the control group.

Participants in the strength training group had significantly greater strength gain than control subjects (*p* = .001 to .06 for different muscle groups). Pretest to posttest strength changes from a representative sample of muscle groups are shown in table 5. Strength changes seen represent about 10% to 16% strength gain for the exercise group and about a 1% gain to 3% decline in the control group. We therefore met our goal to generate a range of strength changes in this sample of frail elders using a randomized clinical trial design.

Relation Between Change in Strength and Change in Function and Disability

Tables 6 through 8 show the results of the linear regression analysis, demonstrating the impact of change in strength on physical performance and disability measured at Time 2 (posttest), controlling for age, depression, baseline strength, and baseline function. There was no effect modification by level of frailty, so the strata were collapsed and the results presented for the full model. Strength gain was significantly associated with gain in mobility skills performance, increase in gait velocity, and gain in falls efficacy. Strength change was not related to change in 6-minute walk distance, functional reach, static sway, or MOS-36, physical scale. Table 9 shows the results of the logistic regression analysis, stratified by level of frailty. For the chair rise task, strength gain appears to have a greater impact in the lower functioning group but not in the higher functioning group. Because frailty level was classified based on chair rise, the lower functioning group was likely, by definition, to have greater potential for gain. However, only a relatively small number of persons improved in chair rise by our definition, making parameter estimates unstable and confidence intervals very wide.

DISCUSSION

This is the first study to directly examine the impact of strength gain on physical performance and disability in frail,

Table 6: Results of Linear Regression Showing Relationship Between Change in Strength and Physical Performance (Mobility and Gait) at Time 2

	Mobility Skills		Gait Speed		Endurance	
	β	*p*	β	*p*	β	*p*
Change in strength	1.35	0.0009	.08	.02	48.2	.12
Age	−.03	0.3	−.0006	0.8	−.04	.98
Depression	−.12	0.8	.01	0.7	15.3	.59
Baseline strength	.33	0.2	.05	0.2	40.5	.03
Baseline performance	.83	.0001	.76	.0001	.81	.0001
Level of frailty	.05	0.9	.02	.47	63.9	.04
Adjusted R^2	.76		.78		.85	

Table 7: Results of Linear Regression Showing Relationship Between Change in Strength and Physical Performance (Balance) at Time 2

	Falls Efficacy		Functional Reach		Spontaneous Sway	
	β	*p*	*β*	*p*	*β*	*p*
Change in strength	10.1	.05	−.07	.87	−.06	0.6
Age	34	0.4	−.04	0.2	−.01	0.4
Depression	5.8	0.2	−.35	0.4	−.13	0.6
Baseline strength	4.7	0.1	.28	.28	−.15	.24
Baseline performance	.56	.0001	.59	.0001	.66	.0001
Level of frailty	1.05	.83	.37	.42	−.21	.36
Adjusted R^2	2.9		.54		.51	

community-dwelling elders. We found that strengthening can be accomplished using a low-technology, in-home, progressive resistive exercise program supervised by a therapist. More importantly, lower extremity strength gain is significantly associated with gains in chair rise ability and in mobility tasks such as gait, transfers, stooping, and stair climbing, but not with improved endurance, balance, or disability. Factors that may influence the ability of strength gain to affect function are (1) initial level of frailty, (2) specificity of exercise and, (3) responsiveness of outcome measures in a frail population.

Initial level of frailty may affect the impact of strengthening on performance. The effect of exercise on chair rise ability appears to be greater in more frail elders in this study. Knee extensor strength might be "above threshold" for the chair rise task in the more fit group, so that further strengthening cannot further improve chair rise function. Our results may be limited by our measure for chair rise. A more responsive measure such as timed chair rise might have been able to pick up change in the higher functioning group as well the lower functioning group and enabled a better estimate of the relationship between strength gain and chair rise ability.

Strength gain affected mobility skills performance in both frailty levels. All participants were likely to have strength "below threshold" because eligibility required performance limitations and the mobility skills protocol tests a broad range of function.

The lack of association between strength change and change in balance or endurance may be explained by (1) variability in performance or (2) specificity of exercise. We found large variability in gait, transfer, and balance after a 2- to 3-month period in both the intervention and control groups. A recent intervention study by Tinetti and coworkers[16] showed similar variability in 3-month performance in controls. Large variability over a few months may be characteristic of frail elders with less stable health status associated with remitting and exacerbating chronic conditions. Treatment effects must be large to overcome such variability in performance.

Specificity of training may partially explain the weak impact of strength gain on balance or endurance. The program we used was specifically designed to strengthen lower extremity muscles at slower speeds of movement. Activities most likely to benefit require strength generated during slow, forceful contractions of the trained muscles, such as chair rise, transfer, stooping, and stair climbing. Balance tasks require specific muscle attributes. Static sway requires quick muscle contractions of low force to maintain the center of gravity over the base of support. Functional reach requires eccentric (controlled lengthening) rather than concentric (shortening) contractions of the plantar flexors. We did not emphasize eccentric plantar flexor strengthening in our exercise program.

Table 8: Results of Linear Regression Showing Relation Between Change in Strength and Disability (MOS-36, Physical Scale) at Time 2

	MOS-36, Physical Scale	
	β	*p*
Change in strength	−2.5	0.6
Age	.51	.09
Depression	4.1	0.3
Baseline strength	0.7	0.7
Baseline MOS-36, physical scale	0.7	.0001
Level of frailty	6.0	.15
Adjusted R^2	.55	

Table 9: Logistic Regression, Stratified by Frailty Level, of Change in Strength and Improved Chair Rise Ability

	β (SE)	*p* Value	Odds Ratio	95% CI
Lower functioning				
Change in strength	3.8 (1.9)	.0	46.7	1.1-1635
Age	−.11 (.07)	.14	.89	.76-1.1
Depression	1.6 (1.0)	.11	5.2	1.6-36.9
Baseline strength	1.6 (.8)	.06	4.8	1-24.5
Higher functioning				
Change in strength	−.26 (.73)	0.7	.77	.18-3.2
Age	.001 (.06)	0.9	1.0	
Depression	.48 (.78)	0.5	1.6	.35-7.5
Baseline strength	0.1 (.4)	0.8	1.1	0.5-2.4

Strength gain appears to be more strongly related to improvement in chair rise in more impaired participants.

Abbreviations: SE, standard error; CI, confidence interval.

Although there was not a relation between strength gain and improvement in measures of balance performance, there was a significant relation between strength gain and falls efficacy scale, suggesting that gain in strength has a positive influence on a person's perception of his or her ability to avoid falls. Our training program may have been of insufficient duration or intensity to have had a more direct impact on measures of balance performance. Findings reported recently showed that a 12-month generalized, low-intensity conditioning program in community-dwelling elderly produced gains in strength similar to those seen in our study, as well as significant changes in static sway. These results suggest that a longer duration of low-intensity exercise may be important in improving balance.[31]

The 6-minute walk distance is a measure of endurance, which was not specifically treated by our program. A recent study in older adults, however, suggests that strength training can also improve endurance.[32] The fact that our training program did not improve endurance may be because we used a lower intensity strengthening program than the one used in that study, resulting in more modest gains in muscle strength. Another possibility is that a low to moderate exercise stimulus like the one in this study may have been too short-term to effect significant change in muscle endurance.

The relation between strength change and change in distal outcomes such as MOS-36 has not been studied. We found no significant effect on MOS-36 (physical scale), a measure that may not have been sensitive to changes in strength or performance seen in our study. MOS-36 may be more sensitive to change in those capable of higher level activities. Relative frailty may be a critical issue when selecting appropriately sensitive outcome measures. The physical activity questions on the MOS-36 probe higher-level physical functions (vigorous activities, walking a mile or a block, climbing stairs) but not in-home mobility such as getting around the house. Frail individuals may improve in tasks not captured by the MOS-36. Selecting the right population with the right measure of disability is essential when studying function as an outcome.

In summary, in the population most in need of programs to improve strength—community-dwelling frail elders—strength gain can be achieved using simple resources. The strength gain achieved in this population and setting with a well-tolerated low- to moderate-intensity program can improve mobility and gait speed. Higher-intensity or longer-duration strength training, or other types of exercise, may be needed to improve balance and endurance.

References

1. Buchner DM, Wagner EH. Preventing frail health. Clin Geriatr Med 1992;8:1-6.
2. Bassey EJ, Fiatarone M, O'Neill E, Kelly M, Evans WI, Lipsitz A. Leg extensor power and functional performance in very old men and women. Clin Sci 1992;82:321-7.
3. Studenski SA, Duncan PW, Chandler JM. Automatic postural responses and effector factors in unexplained falls. J Am Geriatr Soc 1991;39:229-34.
4. Whipple RH, Wolfson LI, Amerman PM. The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. J Am Geriatr Soc 1987;35:13-20.
5. Gehlsen GM, Whaley MH. Falls in the elderly; Part II: balance, strength, and flexibility. Arch Phys Med Rehabil 1990;71:739-41.
6. Hyatt RH, Whitelow MN, Bhat A, Scott S, Maxwell JD. Association of muscle strength with functional status of elderly people. Age Ageing 1990;19:330-6.
7. Aniansson A, Ljundberg P, Rudgren A, Wetterquist H. Effect of a training program for pensioners on condition and muscular strength. Arch Gerontol Geriatr 1984;3:229-41.
8. Grimby G, Aniansson A, Hedberg M, Henning GB, Grangard U, Kvist H. Training can improve muscle strength and endurance in 78-84 year old men. J Appl Physiol 1992;23:2517-23.
9. Frontera W, Meredith C, O'Reilly KP, Evans WJ. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. J Appl Physiol 1988;64:1038-44.
10. Fiatarone M, Marks E, Ryan N, Meredith CN, Lipsitz LA, Evans WI. High intensity strength training in nonagenarians. JAMA 1990; 263:3029-34.
11. Judge JO, Whipple RH, Wolfson LI. Effects of resistive and balance exercises on isokinetic strength in older persons. J Am Geriatr Soc 1994;42:937-46.
12. Fiatarone M, O'Neill EF, Ryan ND, Clements KM, Solares GR, Nelson ME, et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. New Engl J Med 1994; 330:1769-75.
13. Fisher NM, Gresham GE, Abrams M, Hicks J, Horrigan D, Pendergast DR. Quantitative effects of physical therapy on muscular and functional performance in subjects with osteoarthritis of the knees. Arch Phys Med Rehabil 1993;74:840-7.
14. Fisher NM, Pendergast DR, Gresham GE, Calkins E. Muscle rehabilitation: its effect on muscular and functional performance of patients with knee osteoarthritis. Arch Phys Med Rehabil 1991;72: 367-74.
15. Buchner D, Beresford AA, Larson EB, LaCroix AZ, Wagner EH. Effects of physical activity on health status in older adults II: intervention studies. Annu Rev Publ Health 1992;13:469-88.
16. Tinetti ME, Baker DI, McAvay G, Claus EB, Garrett P, Gottschalk M, et al. A multifactorial intervention to reduce the risk of falling among elderly people living in the community. New Engl J Med 1994;331:821-7.
17. Reuben DB, Laliberte L, Hiris J, Mor V. A hierarchical exercise scale to measure function at the advanced activities of daily living (AADL) level. J Am Geriatr Soc 1990;38:855-61.
18. Folstein MF, Robins LN, Helzer JE. The minimental state examination. Arch Gen Psychiatry 1983;40:812.
19. Anthony JE, LeResche L, Niaz U, Von Korff MR, Folstein MF. Limits of the mini-mental state of a screening test for dementia and delirium among hospital patients. Psychol Med 1982;12:397-408.
20. Studenski SA, Duncan PW, Chandler JM, Samsa G, Prescott B, Hogue C, et al. Predicting falls: the role of mobility and nonphysical factors. J Am Geriatr Soc 1994;42:297-302.
21. Chandler JM, Duncan PW, Samsa G, Studenski SA. Choosing the best strength measure: importance of task specificity. Muscle Nerve 1997;Suppl 5:S47-S51.
22. Duncan PW, Weiner DK, Chandler J, Studenski S. Functional reach: a new clinical measure of balance. J Gerontol 1990;45:M192-7.
23. Tinetti ME, Richman D, Powell L. Falls efficacy as a measure of fear of falling. J Gerontol 1990;45:P239-43.
24. Guyatt GH, Thompson PJ, Berman LB, Sullivan MJ, Townsend M, Jones NL, et al. How should we measure function in patients with chronic heat and lung disease? J Chronic Dis 1985;38:517-24.
25. Guyatt GH, Sullivan MJ, Thompson P, Fallen EL, Pugsley SO, Taylor DW, et al. The 6 minute walk: a new measure of exercise capacity in patients with chronic heart failure. Can Med Assoc J 1985;132:919-23.
26. Guyatt GH, Pugsley SO, Sullivan MJ, Thompson PJ, Berman L, Jones NL, et al. Effect of encouragement on walking test performance. Thorax 1984;39:818-22.
27. Hogue CC, Studenski SA, Duncan PW. Assessing mobility: the first step in preventing falls. In: Funk SG, Tornquist EM, Champagne MP, Coop LA, Weise RA, editors. Key aspects of recovery: improving nutrition, rest, and mobility. New York: Springer; 1990. p. 275-80.
28. Weiner DK, Duncan PW, Chandler JM, Studenski SA. Functional reach: a marker of physical frailty. J Am Geriatr Soc 1992;40:203-7.
29. McHorney CA, Ware JE, Rogers N, Raczek AE, Lu JF. The validity and relative precision of MOS short- and long-form Health Status Scales and Dartmouth Coop Charts. Med Care 1992;30:MS253-MS265.
30. Koenig HG, Cohen HJ, Blazer DG, Meador KG, Westlund R. A brief depression scale for use in the medically ill. Int J Psychiatry Med 1992;22:183-95.
31. Lord SR, Ward JA, Williams P, Strudwick M. The effect of a 12-month exercise trial on balance, strength, and falls in older women: a randomized controlled trial. J Am Geriatr Soc 1995;43:1198-1206.
32. Ades PA, Ballor DL, Shikaga T, Utton JL, Nair KS. Weight training improves walking endurance in healthy elderly persons. Ann Intern Med 1996;124:568-72.

Suppliers

a. Cybex, Lumex, Inc., 2100 Smithtown Avenue, Ronkonkoma, NY 11779.
b. Model 01160; Lafayette Instrument Company Inc., Lafayette, IN.
c. SAS Institute, Cary, NC.

APPENDIX A: DESCRIPTION OF EXERCISE INTERVENTION

This progressive resistance exercise program incorporates the physiologic principles of overload and specificity and is consistent with American College of Sports Medicine guidelines for strength training. The exercises are designed to improve lower extremity strength at slow velocities of movement. The muscle groups targeted in this program include ankle plantar and dorsiflexors, knee extensors and flexors, and hip extensors and abductors. After a 5-minute warm-up consisting of gentle stretching and marching in place, each participant was systematically positioned to perform exercises for each of the muscles groups identified.

Theraband, a color-coded series of elastic bands with varying tensions, was used to provide progressive resistance to the muscles. Different theraband colors identify the strength of the resistance applied. Progression in colors in ascending order of resistance is yellow, red, green, blue, black, and silver. Participants were started at a theraband color for each muscle that was consistent with their initial strength capacity. The starting level of theraband was determined by finding the point at which the participant could perform 6 to 8 repetitions of the exercise with good quality (eg, full range of motion, no substitution by other muscle groups) before fatigue. The participant exercised 3 times per week, progressing to two sets of 10 repetitions for each exercise. Once the participant could perform two sets of 10 easily at a given color of theraband, the resistance was increased by replacing the theraband with the next color. In some instances, participants increased in strength beyond the silver (strongest) band for some muscle groups (quadriceps, for example). In these cases, another band of black was added to the silver to give the necessary added resistance. During the course of the 10-week intervention, therapists used these guidelines, coupled with their clinical knowledge, to determine the appropriate time for and amount of increased resistance for each participant.

APPENDIX B: STANDARDIZATION OF STRENGTH SCORES

To create summary strength scores or indices that represent bilateral, functionally related muscle groups, we considered it important to account for (1) gender differences in strength scores and (2) differences in relative force-generating capacity of different muscle groups. To do this we chose to standardize each muscle group to a gender-specific mean and standard deviation, such that

$$X_i = \frac{X_i - \overline{X}}{s}$$

where X_i equals the individual's muscle strength score for a particular muscle group (X), $\overline{X}$ equals the gender-specific group mean for that particular muscle group; and s is the standard deviation for that muscle group. A strength score based on peak torque generated during isokinetic contraction of bilateral knee extensor would be calculated as follows:

Standardized bilateral knee extensor score (SKE_i)

$$= \frac{\text{Right knee extensor}(RKE_i) + \text{Left knee extensor } (LKE_i)}{s(RKE + LKE)}$$

A separate index would be similarly created for a strength score based on work generated during isokinetic contraction of bilateral knee extensor or for a strength score based on peak torque generated during an isometric contraction of bilateral knee extensor. Indices that involve the sum of different, functionally related muscle groups follow the same process. Creation of a proximal-distal index that includes standardized knee extensor and standardized ankle extensor [bilateral knee extensor (SKE_i), as above, and bilateral plantar flexors (SPF_i)] would be carried out as follows:

Standardized knee-ankle extensor index ($SK\text{-}A_i$)

$$= \frac{(SKE_i) + (SPF_i)}{s\ (SKE + SPF)}$$

Using a similar process, we created standardized strength variables for six different combinations of lower extremity muscle groups that were previously shown to be the most strongly correlated with the specific performance and disability measures of interest. Table 1 shows the strength measures that were created and the specific tasks they were shown to represent best.