Training-Induced Strength and Functional Adaptations After Hip Fracture

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Background and Purpose

At 3 months after hip fracture, most people are discharged from physical therapy despite residual muscle weakness and overall decreased functional capabilities. The purposes of this study were: (1) to determine, in frail elderly adults after hip fracture and repair, whether a supervised 6-month exercise program would result in strength gains in the fractured limb equivalent to the level of strength in the nonfractured limb; (2) to determine whether the principle of specificity of training would apply to this population of adults; and (3) to determine the relationship between progressive resistance exercise training (PRT) intensity and changes in measures of strength and physical function.

Subjects

The study participants were 31 older adults (9 men and 22 women; age [$\bar{X}\pm SD$], 79±6 years) who had surgical repair of a hip fracture that was completed less than 16 weeks before study enrollment and who completed at least 30 sessions of a supervised exercise intervention.

Methods

Participants completed 3 months of light resistance and flexibility exercises followed by 3 months of PRT. Tests of strength and function were completed at baseline, before PRT, and after PRT.

Results

After PRT, the subjects increased knee extension and leg press 1-repetition maximum by 72%±56% and 37%±30%, respectively. After 3 and 6 months of training, lower-extremity peak torques all increased. Specificity of training appeared to apply only to the nonfractured limb after PRT. Strong correlations were observed between training intensity and lower-extremity strength gains as well as improvements in measures of physical function.

Discussion and Conclusion

Frail elderly adults after hip fracture can benefit by extending their rehabilitation in a supervised exercise setting, working at high intensities in order to optimize gains in strength and physical function.

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With aging, there is a decline in muscle mass and function.[1–5] Older adults with muscle weakness and physical frailty are at increased risk for hip fracture, a leading cause of disability in the population of frail older adults.[6–9] Magaziner et al[6] showed that functional deficits remain even at 2 years after hip fracture in older adults. Studies of elderly adults with various degrees of physical frailty have demonstrated that such people are capable of increasing their strength (force-generating capacity) and functional performance in response to progressive resistance exercise training (PRT) programs.[10–18]

The concept of exercise training specificity was first established by DeLorme[19] and has been further supported by the results of others.[20–23] With resistance exercise training, specifically, gains that are made have been shown to be specific to the type[21] and speed[20] of movement. Frontera et al[10] also showed that specificity of training occurs in older men who are healthy (age range=60–72 years). More recent studies of community-dwelling older people with hip fracture have shown that significant strength gains can be made after high-intensity resistance exercise programs.[24–26]

There is evidence to suggest that in frail older people, a small improvement in physiological capacity (including improvements in muscle strength) can have a substantial effect on functional performance.[27] Furthermore, the more fit an elderly individual, the smaller the association between lower-extremity (LE) strength and functional performance.[27–30] Buchner et al[27] showed there was a nonlinear relationship between leg strength and gait speed; that is, in stronger subjects, there was no association between strength and gait speed, whereas in weaker subjects, there was a demonstrable association.

Several investigators[31–37] have highlighted the need for more studies to determine the type and amount of exercise intervention necessary to maintain or enhance an elderly individual's strength and function. For community-dwelling elderly people who are healthy, several studies have elucidated the most appropriate exercise type, intensity, and frequency that result in skeletal muscle hypertrophy and concomitant increases in strength.[10–12,15,16,38–40] Briefly, in a supervised setting, a program of PRT lasting from 10 weeks to 2 years, ranging from low intensity to high intensity,[38] and ranging in frequency from 1 to 3 times per week[39] can result in improvements in both muscle strength and cross-sectional area in community-dwelling elderly people.[10–12,15,16,38–40] The optimal prescription for exercise intensity, frequency, and duration for people after hip fracture and repair has yet to be determined.

The aim of this study was to determine, in frail elderly adults after hip fracture: (1) whether a supervised program of PRT would result in improvements in LE muscle performance, bringing the fractured limb to at least the level of that of the nonfractured limb; (2) whether the principle of specificity of training would apply, that is, whether resistance training at relatively slow speeds would result in muscle performance improvements (including functional task performance measures) only at slow speeds; and (3) whether a relationship exists between exercise intensity and resultant improvements in strength and function (dose-response relationship). Our ultimate goal is to guide rehabilitation specialists in devising exercise programs that will optimize an individual's strength and function after hip fracture and repair.

Method

The details of the study design and method have been reported elsewhere[25] and are summarized below.

Subjects

Men and women aged 65 years or older and with a recent proximal femur fracture were recruited from local hospitals, home-care programs, and the community at large to participate in this study. People were recruited close to the time of discharge from physical therapy, which, in most cases, was completed at home. After a brief telephone interview, potential participants were invited to undergo a screening evaluation, which included a medical history, medical record review, physical examinations by a physician and a physical therapist, blood and urine chemistry analyses, electrocardiogram, and the Short Blessed Test (SBT) of Orientation, Memory, and Concentration.[41]

We administered a modified version of the Physical Performance Test (PPT), a 9-item evaluation of physical function developed by Reuben and Siu.[42] The scores on the PPT range from 0 to 36 and are associated with degree of disability, loss of independence, and mortality in elderly people.[42,43] Our modified PPT substitutes the timed chair stand and standing balance tasks developed by Guralnik and colleagues[44,45] for the writing and simulated eating items in the original PPT.[46] The reliability of scores on the modified PPT has been studied and have been demonstrated to be reproducible.[47]

Self-reported information regarding activities of daily living (ADL) and instrumental ADL were collected with 3 standardized, validated questionnaires.[48–50] Written informed consent was obtained from subjects in accordance with procedures approved by the Washington University Institutional Review Board.

To be eligible for this study, volunteers had to meet the following criteria: (1) age of ≥65 years, (2) community dwelling (not living in a nursing home) upon discharge from physical therapy for the hip fracture, (3) screening evaluation within 16 weeks of hip fracture repair, (4) modified PPT scores of 12 to 28, and (5) self-reported difficulty or requirement for assistance with one or more ADL. The PPT criterion was devised because we aimed to target people with persistent mobility impairments.

Volunteers were ineligible for the study for any of the following reasons: (1) pathological fracture, bilateral femur fractures, or previous contralateral femur fracture; (2) inability to provide informed consent because of dementia or cognitive impairment or an SBT score of ≥11; (3) inability to walk 15 m (50 ft) (with an assistive device, if needed); (4) visual or hearing impairments that interfered with following directions or that were judged to potentially interfere with performing exercises safely; (5) cardiopulmonary disease or neuromuscular impairments that would contraindicate participation in a weight training program (eg, unstable angina or congestive heart failure, spinal stenosis, symptomatic spondylosis); (6) conditions that might not be expected to improve with exercise training (severe Parkinson disease or cerebrovascular disease with residual hemiparesis); (7) initiation of medication for osteoporosis or hormone therapy within 12 months of screening; and (8) terminal illness with a life expectancy of less than 1 year.

Design

Random assignment to the exercise intervention group or a control group was performed upon completion of the baseline assessments within strata defined as the type of surgical repair procedure (hemiarthroplasty versus open reduction and internal fixation) by use of a computer-generated algorithm and a block design. Subjects who were unable or unwilling to drive to our research facility were provided transportation for all assessment and exercise sessions. The results of the intention-to-treat analysis were reported previously by Binder et al.[25] This report focuses on the training-induced adaptations of the exercise intervention group.

Outcome Assessments

People enrolled in the study underwent a series of assessments at baseline, with follow-up at 3 and 6 months after baseline, as described below with standardized procedures that included assessments of muscle strength, gait speed, and physical function (as measured with the 9-item modified PPT).[46] The maximum voluntary muscle strength for knee extension, knee flexion, and ankle plantar flexion of the fractured and nonfractured limbs was measured by Cybex* isokinetic dynamometry as previously described.[51,52]

In brief, 3 different muscle groups were assessed with the subject in a seated position: knee extensors, knee flexors, and ankle plantar flexors. The plantar flexors were assessed at 0°/s, 60°/s, and 120°/s, and the knee movements were assessed at 0°/s, 60°/s, and 180°/s. Isometric (0°/s) knee strength was assessed with the knee flexed 45 to 60 degrees from full extension. Ankle isometric plantar-flexor strength was assessed with the ankle in a neutral position (knee flexed 10°). Gait speed was measured over a distance of 15.24 m for a subject's self-selected and maximum walking speeds; this speed was assessed with a handheld digital stopwatch and was recorded to the nearest 0.1 second. The research staff members who conducted all of the assessments were not involved in any exercise training and were unaware of group assignment.

* Cybex International Inc, 10 Trotter Dr, Medway, MA 02053.

Supervised Exercise Training

The supervised exercise training program was conducted at an indoor exercise facility located at our medical center campus. It consisted of 2, approximately 3-month-long phases of exercise training. Exercises during the first 3-month phase (phase 1) were conducted by a physical therapist using a group format (2–5 subjects per group) and were designed to enhance flexibility, balance, coordination, movement speed and, to some extent, the strength of all major muscle groups. Twenty-two exercises formed the basis of this program (protocol available upon request). The exercises were made progressively more difficult by increasing the number of repetitions and by having the subjects perform the exercises in more challenging ways. The exercises were modified by the physical therapist to accommodate and target each subject's specific physical impairments as previously described.[25]

At the therapist's discretion, subjects also exercised on a stationary bicycle or treadmill. Subjects performed this exercise for a minimum of 5 minutes and progressed to a maximum of 15 minutes. The treadmill speed or bicycle resistance was set at the highest comfortable setting that was safe for the subjects. A formal aerobic exercise training protocol was not prescribed or performed. Exercise sessions lasted 45 to 90 minutes (with breaks), depending on the subjects' ability and tolerance, which increased over the course of phase 1.

During the second exercise phase (phase 2), PRT was added. The maximum weight that each subject was able to lift completely (1-repetition maximum [1-RM]) was measured for each of 3 different exercises (knee extension, knee flexion, and leg press), which were performed bilaterally on a Hoist weight lifting machine.[†] After the 1-RM had been established for each exercise, each subject performed 1 or 2 sets of 6 to 8 repetitions of each exercise at 65% their 1-RM. In our study, as is typical of most PRT protocols, training was performed at a fairly slow speed of limb movements (following American College of Sports Medicine recommendations, subjects were instructed to have a 1- to 2-second concentric contraction followed by a 1- to 2-second eccentric contraction for each exercise[53]). Measurement of several of our study participants during exercise performance (with a handheld stopwatch and goniometer) revealed that the participants were lifting weights at limb speeds of ~40° to 45°/s for all LE exercises.

By the end of the first month of weight training, subjects were asked to perform 3 sets of 8 to 12 repetitions at 85% to 100% their initial 1-RM. The 1-RM measurements were repeated at 6 weeks (18 sessions) and used to progressively increase each subject's exercise prescription. The 1-RM also was assessed during the final week of resistance training (after PRT [post-PRT]). Subjects continued to perform a shortened version of the phase 1 exercises (focusing on balance, flexibility, and core abdominal exercises) and the treadmill or stationary bicycle warm-up exercise throughout the PRT phase of the program. This portion of each workout session took ~30 minutes to perform, with the remaining 60 minutes typically being spent on PRT.

Subjects were expected to attend exercise sessions 3 times per week and to complete 36 sessions of each exercise phase before progression to the next phase of exercise training and program completion. Subjects who missed exercise sessions because of illness or brief vacations were allowed to make up the sessions, up to a maximum of 9 sessions. For our analysis, results are reported only when a participant completed a minimum of 30 (83%) of both phase 1 and phase 2 (PRT) exercise sessions during the 3-month-long phases. This strategy was required to ensure that the duration of the exercise program was equivalent for the studied group.

[†] Hoist Fitness Systems Inc, 9990 Empire St, Suite 130, San Diego, CA 92126.

Table 1.
Baseline Characteristics of Subjects

Variable[a]	Value for Subjects in Supervised Exercise Group (N=31)
Age, y, $\overline{X}$±SD	79±6
Sex, %	
Male	29
Female	71
Height, cm, $\overline{X}$±SD	163.5±11.1
Weight, kg, $\overline{X}$±SD	66.0±17.8
Body mass index, kg/m^2	24.5±5.0
Education level, y, $\overline{X}$±SD	12.4 ±2.8
Time since surgical repair of fracture, wk, $\overline{X}$±SD	12.1±3.6
Fracture type (no. of subjects)	
Subcapital	17
Intertrochanteric	14
Surgical repair (no. of subjects)	
Hemiarthroplasty (posterolateral approach)	14
Open reduction-internal fixation	17
Use of assistive device (no. of subjects)	
Wheeled walker	11
Quad cane	5
Straight cane	8
None	7
FSQ score, $\overline{X}$±SD	22±6
BADL score, $\overline{X}$±SD	10±2
IADL score, $\overline{X}$±SD	12±2
PPT score, $\overline{X}$±SD	22.1±5.0

[a] BADL=basic activities of daily living, FSQ=Functional Status Questionnaire, IADL=instrumental activities of daily living, PPT=Physical Performance Test.

Data Analysis

For data analysis, we included data only from participants in the supervised PRT group who completed at least 30 sessions in each of the 2 exercise phases. Participants were not separated by sex because there was no gender difference in training intensity, the percent increases achieved with the lower extremity exercises, or with any of the func-

Table 2.
Isokinetic Peak Torque Values at Baseline and After Progressive Resistance Exercise Training (PRT) (N=31)

Measure	Fractured Limb, $\overline{X}\pm SD$			% Increase[a]	
	Baseline	Pre-PRT	Post-PRT	Pre-PRT	Post-PRT
Knee extension (N·m)					
0°/s	64.8±24.9	78.1±32.4[b]	94.6±35.8[b]	24±35	31±43
60°/s	48.4±20.0	65.5±31.7[b]	77.3±29.7[b]	41±50	29±52
180°/s	26.8±15.1	39.5±25.6[b]	47.8±28.5[b]	52±48	35±53
Knee flexion (N·m)					
0°/s	35.3±15.3	48.6±20.4[b]	53.3±21.4[b]	41±44	19±27
60°/s	39.9±16.0	52.6±25.7[b]	61.2±22.3[b]	31±44	45±99
180°/s	24.9±15.0	37.1±20.6[b]	45.9±21.0[b]	55±99	62±131
Ankle plantar flexion (N·m)					
0°/s	34.8±23.5	50.3±31.1[d]	63.8±28.5[d]	111±253 (41)	77±127 (28)
60°/s	26.7±22.2	42.0±29.1[d]	53.7±27.3[d]	198±472 (53)	69±107 (38)
120°/s	18.1±15.7	28.5±22.7[d]	36.8±22.4[d]	136±290 (55)	132±266 (33)

[a] Values in parentheses are the median percent increases reported as a result of nonnormal distribution of initial plantar-flexor peak torque values.
[b] $P<.05$, as determined by 1-way analysis of variance (ANOVA) (baseline vs pre-PRT vs post-PRT).
[c] $P<.05$, as determined by 1-way ANOVA (nonfractured vs fractured knee extension, at baseline).
[d] $P<.01$, as determined by 1-way analysis of covariance (pre-PRT vs post-PRT, with baseline as covariant).

tional measures at baseline, 3 months, or 6 months. Data are presented as means ± standard deviations. To evaluate the training-induced differences between the fractured and the nonfractured limbs, various analyses were performed. First, to evaluate the training-induced differences at 3 time points (baseline, before PRT [pre-PRT], and post-PRT), a 1×3 repeated-measures analysis of variance was performed, and then Tukey *post hoc* testing was performed. Because of the abnormal data distribution of the baseline plantar-flexor peak torque values, an analysis of covariance was used to evaluate the differences between the plantar-flexor peak torque values at pre-PRT and post-PRT time points, with baseline peak torque set as the covariate.

Second, to examine whether training at slow speeds induced differences at the other speeds, a 2×3 analysis of variance with the Tukey *post hoc* test was used to compare the fractured and nonfractured limb post-PRT torque values at all 3 speeds. Third, to evaluate the relationship between measures of training intensity and strength and function, a Pearson correlation coefficient was used. In general, to determine differences between pre-PRT and post-PRT data, *post hoc* pair-wise comparisons were made by use of *t* tests with Bonferroni corrections. Specifically, this analysis was used for assessment of the 1-RM data (comparing pre-PRT and post-PRT measures) and measures of physical function (baseline versus post-PRT measures).

The PRT exercise intensity is represented in several ways: as the 1-RM, as a percentage of the initial 1-RM, and as the PRT exercise volume (volume=average weight lifted during the final week of PRT × average number of repetitions performed during that same time period). In addition, the average intensity of PRT was calculated as the average amount of weight lifted over a set time frame (eg, over all of phase 2 [3 months] or during the final week of training). We report these data to provide clinicians with a measure of relative exercise intensity and prescribed exercise volume and to completely describe our PRT program. For statistical tests, the alpha level was set at $P<.05$. Systat version 11.0[‡] was used for all analyses.

Results

Study Population

Of the 46 participants assigned to the supervised exercise group, 31 participants completed at least 30 of the 36 possible sessions of both phases of the program and were therefore included in our analysis. The baseline characteristics of the subjects are shown in Table 1.

Comparison of Fractured and Nonfractured Limbs

At baseline, all of the major muscle groups assessed (knee extensors,

[‡] Systat Software Inc, 1735 Technology Dr, San Jose, CA 95110.

Nonfractured Limb, $\bar{X}\pm SD$			% Increase[a]	
Baseline	Pre-PRT	Post-PRT	Pre-PRT	Post-PRT
79.1±33.6[c]	87.6±29.4[b]	102.7±36.3[b]	54±245	19±24
68.4±30.1[c]	75.9±29.1[b]	87.0±29.7[b]	21±50	18±21
42.8±22.7[c]	48.1±25.8	56.7±28.4	24±54	34±77
41.9±17.5	48.2±21.6[b]	59.9±22.2[b]	20±45	33±42
47.3±21.1	55.3±23.1[b]	67.7±24.4[b]	35±95	31±36
32.7±19.9	38.9±21.2[b]	46.4±22.2[b]	67±203	38±60
40.2±28.4	58.5±31.6[d]	64.1±34.0[d]	98±150 (52)	46±132 (13)
34.4±24.3	46.4±31.6[d]	53.7±29.0[d]	71±170 (41)	95±247 (19)
23.5±18.0	31.3±25.1[d]	35.8±23.7[d]	83±251 (21)	39±80 (26)

knee flexors, and ankle plantar flexors) were weaker in the fractured limb than in that of the nonfractured limb, although this difference reached statistical significance only for the knee extensors ($P<.05$ for all 3 isokinetic speeds) (Tab. 2). Knee extensor (Figure, graphs A and B), knee flexor, and plantar-flexor peak torque values for both the fractured and the nonfractured extremities increased ($P<.05$) from baseline values (Tab. 2). An exception to this trend was noted for the knee extensors of the nonfractured limb at 180°/s (Figure, graph B). The increases in peak torque values as a result of training suggest that specificity of training applied largely to the nonfractured limb, with the fractured limb showing diminished adaptation.

After the PRT phase of the program, the knee extensor peak torque values for the fractured limb remained lower than those for the nonfractured limb at all 3 isokinetic speeds tested, but the difference did not reach significance (Figure, graph C). In addition, hamstring and plantarflexor muscle peak torque values were essentially equivalent for the fractured and nonfractured limbs after the PRT phase of the program.

Specificity of Training

As described above in the comparison of the fractured and nonfractured limbs, bilateral weight training resulted in increases in peak torque values for both the fractured and the nonfractured limbs. An exception to this trend was noted for the nonfractured limb at the fastest speed tested, 180°/s (Figure, graph B). These data indicate that specificity of training applied only to the nonfractured, more "fit" limb and not to the fractured limb.

Dose-Response Relationship for the PRT Program

There was a strong relationship between the weight lifting intensity and the peak torque production for the quadriceps femoris and hamstring muscle groups. This finding was evident from the high correlations between the 1-RM measures recorded during the final week of training and the post-PRT isometric torque production measured for the quadriceps femoris and hamstring muscle groups (Tab. 3). The relationship between weight lifting intensity and plantar-flexor strength, although not as robust, was still evident at 60°/s and 120°/s (approaching significance for nonfractured limb, with $P=.058$).

Training Intensity and Results of the PRT Program

Throughout phase 2 of the exercise program, the subjects worked at an average intensity of 84%±5% their initial 1-RM for the knee extensors. During the final week of PRT, they were training at an average intensity of 107%±4% their initial 1-RM and averaged 25±2 repetitions. The maximum weight lifted during the knee extension exercise increased by 72%±56% ($P<.01$) (Tab. 4). During the knee flexion exercise, the sub-

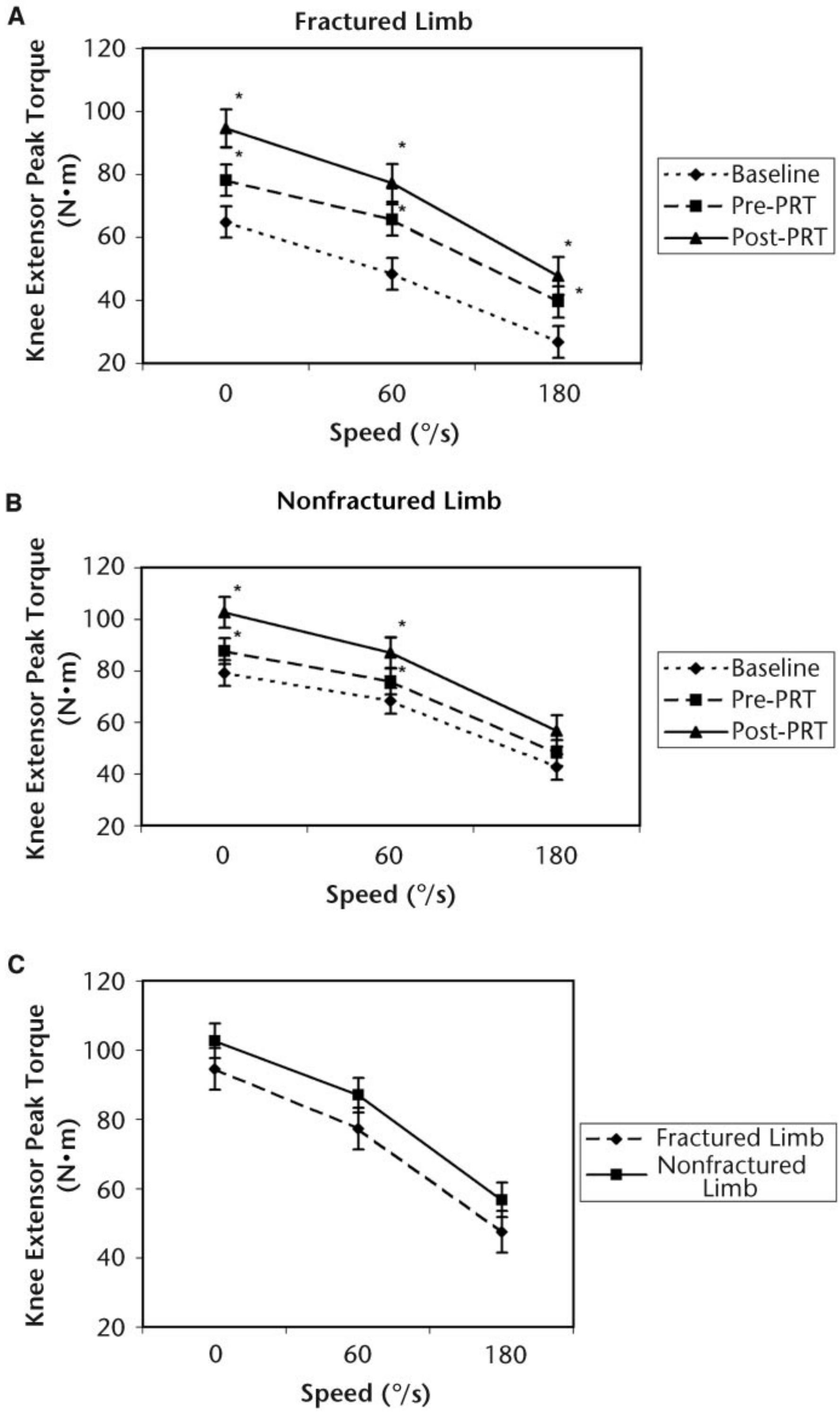

Figure.

(A) Changes in knee extensor peak torque measures from baseline to time points before progressive resistance exercise training (pre-PRT) (after 3 months of supervised exercise training) and after progressive resistance exercise training (post-PRT) (after 6 months of supervised exercise training) in the fractured limb. Data are means ± standard errors. All measures at a single speed were significantly different from one another, that is, $P<.05$ (*) for post-PRT vs pre-PRT vs baseline. (B) Changes in knee extensor peak torque measures from baseline to time points pre-PRT (after 3 months of supervised exercise training) and post-PRT (after 6 months of supervised exercise training) in the nonfractured limb. Data are means ± standard errors. Peak torque measures at 0°/s and 60°/s were significantly different from one another, that is, $P<.05$ (*) for post-PRT vs pre-PRT vs baseline. (C) Knee extensor peak torque measures after 6 months of supervised exercise training (post-PRT) in the fractured and nonfractured limbs.

jects worked at an average of 82%±3% their initial 1-RM throughout the 3-month program. During the final week of PRT, they worked at an average of 98%±3% their initial 1-RM and averaged 25±1 repetitions. The knee flexor 1-RM increased by 20%±22%. The leg press 1-RM increased by 37%±30% ($P<.01$), with participants working at an average of 97%±6% their initial 1-RM during the final week of training, and they averaged 29±2 repetitions. For the leg press, the average training intensity throughout phase 2 of the program was 78%±5% of the initial 1-RM.

Strength Gains Related to Functional Improvements

The total modified PPT score improved 45%±9% ($P<.01$) from the baseline (initial score, 22±5; final score, 30±5). Improvements also were evident for preferred walking speed (40%±5%; $P<.01$), fast walking speed (41%±6%; $P<.01$), and the timed stair climb (36%±4%; $P<.01$) (Tab. 5). Additionally, at the end of the 6-month exercise program, 22 people walked without any type of assistive device; only 7 people did so at baseline. Weight training intensity was strongly correlated with the final (post-PRT) functional measurements (Tab. 6). After the PRT phase of the program, the leg press 1-RM and the knee extension exercise volume (weight × repetitions) were both significantly related to the subjects' final PPT scores. Additionally, there was a significant correlation between the volume of knee extension exercise performed and fast walking speed after the PRT phase of the program. Preferred gait speed was significantly correlated with all of our 1-RM strength measures, including the leg press, knee extension, and knee flexion.

Discussion

Strength Improvements

In contrast to the results obtained by Hauer et al,[24] we observed signifi-

Table 3.
Correlation of Weight Lifted During 1-Repetition Maximum (1-RM) and Peak Torque at 3 Speeds in Fractured and Nonfractured Limbs

1-RM	Peak Torque Production	r	P^a
Leg press (n=24)			
Knee extension	0°/s		
	Fractured	.76	<.001
	Nonfractured	.82	<.001
	60°/s		
	Fractured	.80	<.001
	Nonfractured	.81	<.001
	180°/s		
	Fractured	.73	<.001
	Nonfractured	.75	<.001
Plantar flexion	0°/s		
	Fractured	.47	NS
	Nonfractured	.47	NS
	60°/s		
	Fractured	.65	<.05
	Nonfractured	.64	<.05
	120°/s		
	Fractured	.70	<.01
	Nonfractured	.58	NS
Knee extension (n=30)	0°/s		
	Fractured	.83	<.001
	Nonfractured	.81	<.001
	60°/s		
	Fractured	.87	<.001
	Nonfractured	.86	<.001
	180°/s		
	Fractured	.91	<.001
	Nonfractured	.88	<.001
Knee flexion (n=30)	0°/s		
	Fractured	.88	<.001
	Nonfractured	.88	<.001
	60°/s		
	Fractured	.84	<.001
	Nonfractured	.89	<.001
	180°/s		
	Fractured	.85	<.001
	Nonfractured	.77	<.001

[a] NS=not significant.

Table 4.
1-Repetition Maximum and Percent Increase for Bilateral Lower-Extremity Exercises After Progressive Resistance Exercise Training

Measure	No. of Subjects[a]	Weight Lifted, kg ($\overline{X}$±SD), for Exercise Group	% Increase ($\overline{X}$±SD)
Knee extension			
Pretraining	31	26.0±18.4	
Posttraining	31	42.8±29.0[b]	72±56
Knee flexion			
Pretraining	31	31.0±15.6	
Posttraining	31	37.5±21.2	20±22
Leg press			
Pretraining	27	29.9±12.5	
Posttraining	25	40.4±16.5[b]	37±30

[a] Only 25 subjects were able to perform the 1-repetition maximum on the leg press machine before and after progressive resistance exercise training.
[b] $P<.01$ for posttraining vs pretraining.

cant gains in strength measures for the fractured limb in all 3 muscle groups, at all 3 speeds, and after both low-intensity and high-intensity types of exercise. One difference between our study and that of Hauer et al[24] is that we observed a significant difference in the baseline knee extensor strength measurements between the fractured and nonfractured limbs, whereas they did not. Their subjects were slightly older, but it appears that they may have been studying a more physically fit, that is, less frail, group of subjects[24] who were able to lift much larger amounts of weight with the leg press exercise at baseline. In addition, a few of the subjects enrolled in their study had elective total hip arthroplasty rather than surgical repair of hip fracture after a fall. Another difference between the 2 studies involved plantar-flexor peak torque values. Hauer et al[24] did not observe a significant increase in plantar-flexor strength in the fractured limb, whereas we observed significant increases after both phase 1 and phase 2 of our exercise program.

Table 5.
Measures of Physical Function (N=31)[a]

Measure	$\overline{X}$±SD		% Improvement, $\overline{X}$±SD
	At Baseline	Post-PRT	
PPT score (range=0–36)	22±5	30±5[b]	45±9
Preferred walking speed (m/min)	48.4±14.4	66.1±17.7[b]	40±5
Fast walking speed (m/min)	55.6±17.2	76.7±24.7[b]	41±6
Timed stair climb (s)	14.0±5.7	8.4±4.6[b]	36±4

[a] PPT=Physical Performance Test, Post-PRT=after progressive resistance exercise training.
[b] $P<.01$ for baseline vs post-PRT.

Specificity of Training

Our study findings suggest that in frail older adults recovering from a recent hip fracture, specificity of training applies only to the nonfractured limb. That is, training at relatively slower speeds results in improvements at slower speeds but does not result in significant increases in peak torque values at relatively faster isokinetic speeds. These results are consistent with the results of a study by Frontera et al.[10] They showed that previously sedentary older men who were healthy and who performed PRT at slow speeds had significant increases in LE peak torque values at slow speeds but not at faster speeds.

Our results suggest that specificity of training does not hold true for the fractured limb. We observed significant increases in the knee extensor peak torque values at all speeds tested (slow to fast) for the fractured limb, despite the fact that the resistance training was performed only at a slower pace (typically between ~40 and 45°/s). This finding may be secondary to persistent weakness in the involved LE, as evidenced by the low peak torque values at baseline. This may suggest that the greater the weakness, the more likely strength gains will be observed at all speeds of movement (slow, moderate, or fast) when assessing improvements in strength in a person following hip fracture and repair. The positive aspect of this finding is that—despite the fact that the training was performed only at a slow pace—strength gains were seen across all speeds (slow, moderate, and fast) for the fractured limb. The reason for this finding is not entirely clear at this time and may warrant further study.

Training Intensity

Consistent with previous studies of PRT,[12,15,34,40] our results demonstrate that training intensity correlates with improvements in voluntary muscle strength and functional measures. To our knowledge, this is the first study to investigate this relationship in people recovering from a hip fracture. The relationship between the plantar flexor peak torque and the leg press 1-RM was the weakest among the 3 muscle groups tested. This finding is most likely attributable to the plantar flexors not being the primary mover during the leg press exercise or a major contributor during knee extension and flexion.

Table 6.
Correlations Between Strength Measures (1-Repetition Maximum [1-RM] and Weight Lifting Volume) and Measures of Function (Physical Performance Test [PPT] Scores)

Strength Measure	Functional Test	*R*	*P*
Leg press 1-RM (n=24)	Final PPT score	.58	.03
	Preferred walking speed	.60	.01
Leg press volume (weight × repetitions)	Preferred walking speed	.55	.04
Knee extension 1-RM (n=30)	Preferred walking speed	.50	.03
Knee extension volume (weight × repetitions)	Final PPT score	.52	.03
	Preferred walking speed	.67	.00
	Fast walking speed	.56	.01
Knee flexion 1-RM (n=30)	Preferred walking speed	.54	.01
	Timed stair climb	−.48	.08
Knee flexion volume (weight × repetitions)	Preferred walking speed	.59	.00
	Fast walking speed	.47	.09

Strength Related to Function

Our study results are consistent with those of Buchner et al,[29] who demonstrated that in elderly subjects with muscle weakness, LE strength and gait speed are highly correlated. We observed a significant correlation between LE strength and both preferred and fast gait speeds. After the PRT phase of the program, the final fast gait speed of 77±25 m/min for our subjects would allow them to cross a standard intersection safely (the minimum speed required is 1.22 m/s or 73.2 m/min),[54] indicating improved function. We also observed a significant correlation between the final 1-RM for the leg press and the final total modified PPT scores. The post-PRT PPT score of 30±5 brought our subjects up to a classification of mild frailty, a significant improvement from the baseline classification.[46] Therefore, for our group of frail older subjects after hip fracture, the observed improvements in LE strength were closely related to functional improvements.

Study Limitations

The present study has several limitations. Because we chose to study people who were not severely frail or highly fit, our results can be generalized only to the subset of people with mild to moderate frailty after hip fracture. Another limitation is that a precise dose-response relationship could not be assessed for the phase 1 exercises because we did not have a quantitative measure of intensity, such as 1-RM, which was used in the PRT phase of the program. Finally, during the PRT phase of the program, our subjects were performing bilateral exercises, but isokinetic strength assessments were performed unilaterally. Our bilateral measures of exercise intensity (whether as the 1-RM, as a percentage of the initial 1-RM, or as the training volume [weight × repetitions]) were all highly correlated with the unilateral measurement of isokinetic peak torque. It remains to be determined whether the relationship between training intensity and strength improvements might have been stronger had unilateral exercise training been performed. It also remains to be determined whether this type of training regimen would result in greater absolute strength gains for the fractured and nonfractured limbs.

Clinical Relevance

The results of the present study, combined with those of a previous randomized control trial,[25] provide evidence that significant strength and functional gains can be achieved by frail elderly people after hip fracture, even after discharge from a traditional rehabilitation program. In addition, the present study demonstrates that people who have had a hip fracture and who work at a higher intensity of PRT will achieve greater gains in strength and physical performance. As a rehabilitation goal, therapists should aim for strength gains that bring the fractured limb at least to the level of that of the nonfractured limb.

A remaining question is whether PRT can be initiated safely before ~5 to 7 months after the surgical repair (when our participants started PRT) and, if so, whether people following hip fracture can achieve strength and functional gains of magnitudes similar to those observed in the present study. In addition, more information is needed to determine a feasible and effective maintenance exercise program for people following hip fracture. There is some evidence suggesting that older adults who are healthy can maintain strength gains through continued PRT, at a minimum of once per week[39] at the intensity[24,38] that they achieved during the PRT program.

Conclusion

The results of the present study show that in frail elderly people after hip fracture and repair, a 6-month supervised exercise program can induce gains in strength such that the fractured limb is essentially equivalent to the nonfractured limb. Second, the concept of specificity of training does not apply to the fractured limb. Finally, there appears to be a strong relationship between exercise training intensity and functional performance adaptations.

Dr Host, Dr Sinacore, and Dr Binder provided concept/idea/project design. Dr Host and Dr Sinacore provided writing. Dr Sinacore, Dr Brown, and Dr Binder provided data collection, and Dr Host, Dr Sinacore, Ms Bohnert, and Ms Steger-May provided data analysis. Dr Sinacore and Dr Binder provided project management, fund procurement, and facilities/equipment. Dr Binder provided subjects.

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References

1 Novak LP. Aging, total body potassium, fat-free mass, and cell mass in males and females between ages 18 and 85 years. *J Gerontol.* 1972;27:438–443.

2 Larsson L, Grimby G, Karlsson J. Muscle strength and speed of movement in relation to age and muscle morphology. *J Appl Physiol.* 1979;46:451–456.

3 Aniansson A, Sperling L, Rundgren A, Lehnberg E. Muscle function in 75-year-old men and women: a longitudinal study. *Scand J Rehabil Med Suppl.* 1983;9:92–102.

4 Fiatarone MA, Evans WJ. The etiology and reversibility of muscle dysfunction in the aged. *J Gerontol.* 1993;48(special number):77–83.

5 Porter MM, Vandervoort AA, Lexell J. Aging of human muscle: structure, function and adaptability. *Scand J Med Sci Sports.* 1995;5:129–142.

6 Magaziner J, Hawkes W, Hebel JR, et al. Recovery from hip fracture in eight areas of function. *J Gerontol A Biol Sci Med Sci.* 2000;55:M498–M507.

7 Marottoli RA, Berkman LF, Cooney LM Jr. Decline in physical function following hip fracture. *J Am Geriatr Soc.* 1992;40:861–866.

8 Magaziner J, Simonsick EM, Kashner TM, et al. Predictors of functional recovery one year following hospital discharge for hip fracture: a prospective study. *J Gerontol.* 1990;45:M101–M107.

9 Koval KJ, Skovron ML, Aharonoff GB, et al. Ambulatory ability after hip fracture: a prospective study in geriatric patients. *Clin Orthop Relat Res.* January 1995:150–159.

10 Frontera WR, Meredith CN, O'Reilly KP, et al. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J Appl Physiol.* 1988;64:1038–1044.

11 Charette SL, McEvoy L, Pyka G, et al. Muscle hypertrophy response to resistance training in older women. *J Appl Physiol.* 1991;70:1912–1916.

12 Fiatarone MA, O'Neill EF, Ryan ND, et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. *N Engl J Med.* 1994;330:1769–1775.

13 Nelson ME, Fiatarone MA, Morganti CM, et al. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures: a randomized controlled trial. *JAMA.* 1994;272:1909–1914.

14 Tinetti ME, Baker DI, McAvay G, et al. A multifactorial intervention to reduce the risk of falling among elderly people living in the community. *N Engl J Med.* 1994;331:821–827.

15 McCartney N, Hicks AL, Martin J, Webber CE. A longitudinal trial of weight training in the elderly: continued improvements in year 2. *J Gerontol A Biol Sci Med Sci.* 1996;51:B425–B433.

16 Yarasheski KE, Pak-Loduca J, Hasten DL, et al. Resistance exercise training increases mixed muscle protein synthesis rate in frail women and men ≥76 yr old. *Am J Physiol.* 1999;277:E118–E125.

17 Fiatarone MA, Marks EC, Ryan ND, et al. High-intensity strength training in nonagenarians: effects on skeletal muscle. *JAMA.* 1990;263:3029–3034.

18 Chandler JM, Hadley EC. Exercise to improve physiologic and functional performance in old age. *Clin Geriatr Med.* 1996;12:761–784.

19 DeLorme TL. Restoration of muscle power by heavy-resistance exercises. *J Bone Joint Surg.* 1945;27:645–667.

20 Coyle EF, Feiring DC, Rotkis TC, et al. Specificity of power improvements through slow and fast isokinetic training. *J Appl Physiol.* 1981;51:1437–1442.

21 Duchataeau J, Hainaut K. Isometric or dynamic training: differential effects on mechanical properties of a human muscle. *J Appl Physiol.* 1984;56:296–301.

22 Dons B, Bollerup K, Bonde-Petersen F, Hancke S. The effect of weight-lifting exercises related to muscle fiber composition and muscle cross-sectional area in humans. *Eur J Appl Physiol Occup Physiol.* 1979;40:95–106.

23 Magel JR, Foglia GF, McArdle WD, et al. Specificity of swim training on maximum oxygen uptake. *J Appl Physiol.* 1975;38:151–155.

24 Hauer K, Specht N, Schuler M, et al. Intensive physical training in geriatric patients after severe falls and hip surgery. *Age Ageing.* 2002;31:49–57.

25 Binder EF, Brown M, Sinacore DR, et al. Effects of extended outpatient rehabilitation after hip fracture: a randomized controlled trial. *JAMA.* 2004;292:837–846.

26 Mangione KK, Craik RL, Tomlinson SS, Palombaro KM. Can elderly patients who have had a hip fracture perform moderate-to high-intensity exercise at home? *Phys Ther.* 2005;85:727–739.

27 Buchner DM, Larson EB, Wagner EH, et al. Evidence for a non-linear relationship between leg strength and gait speed. *Age Ageing.* 1996;25:386–391.

28 Danneskiold-Samsoe B, Kofod V, Munter J, et al. Muscle strength and functional capacity in 78–81-year-old men and women. *Eur J Appl Physiol Occup Physiol.* 1984;52:310–314.

29 Buchner DM, Cress ME, Esselman PC, et al. Factors associated with changes in gait speed in older adults. *J Gerontol A Biol Sci Med Sci.* 1996;51:M297–M302.

30 Buchner DM, Cress ME, de Lateur BJ, et al. The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults. *J Gerontol A Biol Sci Med Sci.* 1997;52:M218–M224.

31 Craik RL. Disability following hip fracture. *Phys Ther.* 1994;74:387–398.

32 Gregg EW, Pereira MA, Caspersen CJ. Physical activity, falls, and fractures among older adults: a review of the epidemiologic evidence. *J Am Geriatr Soc.* 2000;48:883–893.

33 Barry BK, Carson RG. The consequences of resistance training for movement control in older adults. *J Gerontol A Biol Sci Med Sci.* 2004;59:730–754.

34 Latham NK, Bennett DA, Stretton CM, Anderson CS. Systematic review of progressive resistance strength training in older adults. *J Gerontol A Biol Sci Med Sci.* 2004;59:48–61.

35 Close GL, Kayani A, Vasilaki A, McArdle A. Skeletal muscle damage with exercise and aging. *Sports Med.* 2005;35:413–427.

36 Shumway-Cook A, Gruber W, Baldwin M, Liao S. The effect of multidimensional exercises on balance, mobility, and fall risk in community-dwelling older adults. *Phys Ther.* 1997;77:46–57.

37 Tinetti ME, Baker DI, Gottschalk M, et al. Home-based multicomponent rehabilitation program for older persons after hip fracture: a randomized trial. *Arch Phys Med Rehabil.* 1999;80:916–922.

38 Taaffe DR, Pruitt L, Pyka G, et al. Comparative effects of high- and low-intensity resistance training on thigh muscle strength, fiber area, and tissue composition in elderly women. *Clin Physiol.* 1996;16:381–392.

39 Taaffe DR, Duret C, Wheeler S, Marcus R. Once-weekly resistance exercise improves muscle strength and neuromuscular performance in older adults. *J Am Geriatr Soc.* 1999;47:1208–1214.

40 Binder EF, Yarasheski KE, Steger-May K, et al. Effects of progressive resistance training on body composition in frail older adults: results of a randomized, controlled trail. *J Gerontol A Biol Sci Med Sci.* 2005;60:1425–1431.

41 Katzman R, Brown T, Fuld P, et al. Validation of a short orientation-memory-concentration test of cognitive impairment. *Am J Psychiatry.* 1983;140:734–749.

42 Reuben DB, Siu AL. An objective measure of physical function of elderly outpatients. *J Am Geriatr Soc.* 1990;38:1105–1112.

43 Reuben DB, Siu AL, Kimpau S. The predictive validity of self-report and performance-based measures of function and health. *J Gerontol Med Sci.* 1992;47:M106–M110.

44 Guralnick JM, Ferrucci L, Simonsick E, et al. Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. *N Engl J Med.* 1995;332:556–561.

45 Guralnick JM, Simonsick E, Ferrucci L. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol Med Sci.* 1996;49:M85–M94.

46 Brown M, Sinacore DR, Binder EF, Kohrt WM. Physical and performance measures for the identification of mild to moderate frailty. *J Gerontol A Biol Sci Med Sci.* 2000;55:M350–M355.

47 Host HH, Sinacore DR, Brown M, Holloszy JO. Reliability of the modified physical performance test in older adults [abstract]. *Phys Ther.* 1996;76:S23.

48 Jette AM, Cleary PD. Functional disability assessment. *Phys Ther.* 1987;67:1854–1859.

49 Fillenbaum GG, Smyer MA. The development, validity, and reliability of the OARS multidimensional functional assessment questionnaire. *J Gerontol.* 1981;36:428–434.

50 Binder EF, Schechtman KB, Ehsani AA, et al. Effects of exercise training on measures of frailty in community-dwelling elderly adults: results of a randomized, controlled trial. *J Am Geriatr Soc.* 2002;50:1921–1928.

51 Herrick C, Steger-May K, Sinacore DR, et al. Persistent pain in frail older adults after hip fracture repair. *J Am Geriatr Soc.* 2004;52:2062–2068.

52 Brown M, Sinacore DR, Ehsani AA, et al. Low-intensity exercise as a modifier of physical frailty in older adults. *Arch Phys Med Rehabil.* 2000;81:960–965.

53 American College of Sports Medicine. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc*. 2002;34:364–380.

54 US Department of Transportation, Federal Highway Administration. *Manual on Uniform Traffic Control Devices: for Streets and Highways.* Washington, DC: US Department of Transportation, Federal Highway Administration; 1988.