Journal of Gerontology: MEDICAL SCIENCES
2004, Vol. 59A, No. 1, 48–61

Review Article

Systematic Review of Progressive Resistance Strength Training in Older Adults

Nancy K. Latham,[1,2] Derrick A. Bennett,[1] Caroline M. Stretton,[3] and Craig S. Anderson[1]

[1]Clinical Trials Research Unit, University of Auckland, New Zealand.
[2]Center for Rehabilitation Effectiveness, Sargent College, Boston University, Massachusetts.
[3]School of Physiotherapy, Auckland University of Technology, New Zealand.

Background. The aim of this systematic review was to quantify the effectiveness of progressive resistance strength training (PRT) to reduce physical disability in older people.

Methods. Randomized controlled trials were identified from searches of relevant databases and study reference lists and contacts with researchers. Two reviewers independently screened the trials for eligibility, rated their quality, and extracted data. Only randomized controlled trials utilizing PRT as the primary intervention in participants, whose group mean age was 60 years or older, were included. Data were pooled using fixed or random effect models to produce weighted mean differences (*WMD*) and 95% confidence intervals (CI). Standardized mean differences (*SMD*) were calculated when different units of measurement were used for the outcome of interest.

Results. 62 trials ($n = 3674$) compared PRT with a control group. 14 trials had data available to allow pooling of disability outcomes. Most trials were of poor quality. PRT showed a strong positive effect on strength, although there was significant heterogeneity (41 trials [$n = 1955$], *SMD* 0.68; 95% confidence interval [CI] 0.52, 0.84). A modest effect was found on some measures of functional limitations such as gait speed (14 trials [$n = 798$], *WMD* 0.07 meters per second; 95% CI 0.04, 0.09). No evidence of an effect was found for physical disability (10 trials [$n = 722$], *SMD* 0.01; 95% CI –0.14, 0.16). Adverse events were poorly investigated, but occurred in most studies where they were defined and prospectively monitored.

Conclusions. PRT results in improvements to muscle strength and some aspects of functional limitation, such as gait speed, in older adults. However, based on current data, the effect of PRT on physical disability remains unclear. Further, due to the poor reporting of adverse events in trials, it is difficult to evaluate the risks associated with PRT.

MUSCLE weakness is associated with reduced walking speed (1) and an increased risk of disability (2) and falls (3) in older people. However, muscle strength can be improved in these individuals, particularly if their muscles are significantly overloaded by training exercises (4). The most frequently used approach to this form of exercise is progressive resistance training (PRT), since participants work against an external force that is increased as strength increases. Despite evidence of benefit from PRT on strength, there is uncertainty about whether these effects translate into changes in substantive clinical outcomes such as prevention of falls and a reduction in physical disability. Most studies have been under-powered to determine the effects of PRT on these outcomes or have included PRT as a component of a multifaceted intervention. Although many recent guidelines and reviews have provided an assessment of the effectiveness of PRT (5–7), we wished to provide a systematic synthesis of the evidence from randomized clinical trials. In particular, we wished to determine whether PRT, as a single exercise intervention, improves strength, functional limitations, and physical disability in older adults.

Methods

Inclusion Criteria

We included only randomized controlled clinical trials of participants who were older adults (i.e., group mean age of 60 years or older) and where PRT was used as the primary intervention. PRT was defined as a strength-training program in which participants exercised their muscles against an external force that was set at a specific intensity for each participant, and this resistance was adjusted throughout the training program. Studies that included other forms of training as part of an exercise program (and not simply part of the warm-up or cool-down) were excluded.

The primary outcome was physical disability, assessed as a continuous measure, and defined conceptually according to the Nagi model as “a limitation in the performance of socially defined roles and tasks (self-care, work, etc.)” (8). Subsequent to undertaking this review, however, the World Health Organization’s International Classification of Functioning, Disability and Health (ICF) was released (9), where disability is defined as an umbrella term for impairments, activity limitations, and participation restrictions.

Thus, according to the ICF, the outcome measures evaluated in this review fall under the domains of impairments, limitations in simple activities (i.e., similar to functional limitations in Nagi's system), and limitations in complex activities (i.e., similar to some aspects of disability in Nagi's model). We included self-report measures of physical disability based on a variety of instruments that were not restricted to basic activities of daily living (ADL) such as the Barthel Index (10), but also covered wider physical domains included in health-related quality of life (HRQOL) such as the Physical Function (PF) domain of the 36-item short-form questionnaire (SF-36) (11). Secondary outcomes were also assessed according to continuous measures that covered the domains of physical impairment (i.e., strength and aerobic capacity) and functional limitations (i.e., balance, chair-rise, gait speed, timed up-and-go). Other secondary outcomes that were assessed as dichotomous endpoints were falls, adverse events, admission to hospital, and death.

Search Strategy

The following databases were searched: MEDLINE (1966–February 1, 2002), EMBASE (1980–February 1, 2002), CINAHL (final search February 1, 2002), Sports Discus (1948–February 1, 2002), PEDRO (final search February 1, 2002), Digital Dissertations (final search February 1, 2002); the Cochrane Controlled Trials Register (final search February 1, 2002) and the registers of the Cochrane Musculoskeletal Injuries Group and the Rehabilitation Field (final search August 30, 2002). Reference lists for all identified studies were inspected for other suitable studies, and relevant review articles and conference proceedings were screened. Experts in the field were contacted for information regarding unpublished trials. No language restrictions were applied.

Quality Assessment and Data Extraction

Two reviewers (N.K.L. and C.M.S.) screened the titles and abstracts from the database searches to identify potentially relevant trials. After complete copies of the articles were obtained, they used the previously defined inclusion criteria to independently select trials and assess quality. During the quality assessment, the reviewers were masked to the authors, institution, journal title, and trial results. They also independently extracted the data. If these data were not reported in a form that enabled quantitative pooling, the authors were contacted for additional information. If the authors could not be contacted or if the information was not available, the trial was not included in the pooling for that specific outcome.

Quantitative Synthesis

Several factors influenced decisions about whether data should be pooled for a particular outcome and what the most appropriate methods were to be used in the analyses. These factors and our approach to synthesizing these data are described below. MetaView version 4.1 was used for all analyses (12).

Clinical and statistical heterogeneity.—Clinical heterogeneity occurs when the study results differ due to patient characteristics, dose response, or preexisting conditions, while statistical heterogeneity occurs when the results are too different to combine via a particular statistical model, as the results violate the underlying assumptions of that statistical model. In some cases, controlling (or removing) clinical heterogeneity may also remove statistical heterogeneity, but the converse is not usually true.

Although several tests of statistical heterogeneity exist, these are known to have low power. For this review, therefore, a conservatively high significance threshold ($p <$ .1) was used in order to rule out the possibility of statistical heterogeneity influencing the results.

Fixed and random effects.—Either fixed or random effects models can be used in the analysis of pooled data. For the fixed effect approach, it is assumed that random sampling error is the only source of variability around the summary effect size. That is, the estimated pooled effect is assumed to reflect a consistent true effect across studies (13). In general, for a fixed effect method, the individual study estimates are combined using weights, with the weights based on the inverse of the variance of the effect size for that study. For a random effects model, the underlying assumption is that the true effect in different studies is randomly positioned about some central value (14). In general, random effects methods also use weights, but the weights are the inverse of the combined "within" and "between" study variation. This approach attempts to account for the statistical heterogeneity between the studies included in a meta-analysis. In this review, we first performed a test of statistical heterogeneity for each outcome. If this was minimal ($p < .1$), a fixed effects meta-analysis was performed. On the other hand, if there was substantial statistical heterogeneity, we searched for possible explanations by conducting subgroup analyses, and, if none were identified, a random effects model was used albeit with cautious interpretation.

Type of outcome.—Different methods were required in the pooling of data, depending on whether the outcome of interest was dichotomous or continuous, and for continuous outcomes, if the same units were used for all measures or not. For continuous outcomes that used different measurement units, standardized units (i.e., standardized mean differences [*SMD*]) were created, with Hedges adjusted g, which is very similar to Cohen's d, but includes an adjustment for small sample bias (13). For the continuous outcomes that used similar units, a weighted mean difference (*WMD*) was computed. Relative risks and 95% confidence intervals (CI) were calculated for dichotomous outcomes.

Additional analyses.—Sensitivity and subgroup analyses (specified a priori) were conducted if the data were sufficient to explore the effect of differences in trial quality, PRT dose, and the health status of participants. In addition, a sensitivity analysis was conducted to determine the effect of removing one of the largest trials.

Results

Initial searches identified 186 trials that appeared eligible for inclusion, but 120 of these did not meet the study inclusion criteria. The main reasons for exclusion were: the study used a combination of exercise interventions (i.e., not PRT alone); the program did not use a standard approach to PRT; the participants were not elderly (i.e., group mean age was not 60 years or older); or the study was not a randomized controlled trial (Table 1). Of the 66 remaining trials, 4 trials were not included in this version of the review because participants were not randomized to a nonexercise control group [i.e., PRT was compared with aerobic training (15–17) or different intensities of PRT were compared with control (18)]. Therefore, this review is based on 62 trials with 3674 participants (Table 2).

The participants in most of the included studies (35 trials) were healthy, community-dwelling older people with no functional limitations (Table 2). In the remaining 27 studies, the participants had a health problem or functional limitation, and were residing in a hospital or residential-care setting. Fourteen of these 27 trials included older people with a variety of specific medical conditions, including osteoarthritis (19–22), peripheral arterial disease (23,24), acute stroke (25), congestive heart failure (26,27), chronic airflow limitation (28), depression (29), low bone mineral density (30), chronic renal insufficiency (31), and recent coronary artery bypass graft surgery (32). In 13 other studies, the trials recruited participants without a single specific health problem, rather they were considered to be frail and/or had a functional limitation on clinical grounds (33–44). Four of these studies were undertaken with participants who were residents of a long-term residential care facility such as a rest home or nursing home (36,40,41,44), while two studies were undertaken in participants while they were receiving care in hospital (34,45).

Most studies included both men and women, but 5 trials included only men (32,41,46–48) and 13 trials included only women (4,26,30,42,49–57). In 29 studies, the mean or median age of the participants ranged from 60 to 69 years, while in 22 studies, the figure was 70 to 79 years, and in 10 studies it was 80 years or more. One trial did not report the mean age. Most training programs took place in the setting of a gym or clinic, where the sessions could be closely supervised. Seven studies were undertaken entirely in the home (19,35,37–40,58), while 7 additional studies mixed the training between home and a gym or clinic (20,42,43,53,59–61).

Most trials (43 trials) evaluated PRT that had a high training intensity and usually involved use of specialized exercise machines. Twelve trials used low-to-moderate intensity PRT, mainly with elastic tubing or bands. In almost all of the trials, PRT was performed two to three times weekly, but there was wide variation in the frequency and duration of the exercises. Although most programs (35 trials) continued PRT for 8 to 12 weeks, the duration ranged from 2 weeks to 78 weeks, and the number of exercises performed in each session varied from 1 to more than 14.

Table 1. Reasons for Exclusion of Trials

Reason for Exclusion	Trials
Not an RCT	(18,76–128)
Mean age <60 years	(129–143)
Combined program—not PRT alone	(144–188)
Training not considered to be PRT	(189–197)
Serious problems with internal validity (i.e., problems with randomization or greater than 30% of participants dropped out)	(198,199)
No control group (compared PRT with aerobic exercise)	(15–17)
Not randomized to PRT or control group (randomized to different PRT intensities)	(18)

Notes: Numbers in parentheses are reference numbers.
RCT = randomized controlled trial; PRT = progressive resistance training.

Trial Methodological Quality

The trials were evaluated to determine whether efforts were made to minimize bias by utilizing design features known to improve internal validity. Thirteen studies stated that they used a blinded assessor for all outcome measures (20,21,25,35,37,39–41,43,53,58,62,63). Five additional studies used a blinded outcome assessor for some, but not all, outcome assessments (19,26,29,31,36). Eighteen studies used an attention control program (19–21,25,26,29,31,35,36,38,40,41,44,50,60,61,63,64). In three of these studies, the control group received "sham exercise" programs (19,26,31). Twenty studies provided information about the method of randomization, which suggested probable concealment of patient/treatment allocation and/or that randomization lists were generated without bias (19,21,25,28,29,34–37,40,42,45–47,49,54,62,63,65,66). Nine studies stated that they used intention-to-treat analysis (19,20,25,26,35,36,52,62,63), but several studies did not include people who adhered poorly to the exercise program (61) or experienced adverse responses (48) in the analyses. There were more dropouts in the PRT group (219 PRT vs 148 control).

Effects of PRT—Impairment Measures

To minimize clinical heterogeneity, data were pooled from one muscle group, the leg extensors, as this was the most frequently evaluated large muscle group in trials of PRT. Table 3 shows the pooled results from 41 trials of PRT compared with a control group involving 1955 participants. There was a significant moderate-to-large beneficial effect of PRT on strength (*SMD* 0.68; 95% CI 0.52, 0.84). However, there was significant statistical heterogeneity apparent in these data (Figure 1). Table 3 also shows that there was no clear effect of PRT on aerobic capacity (*SMD* 0.13; 95% CI –0.02, 0.27) based on 777 participants (20,23–29,32,37,48,62,65,67–69). However, a different pattern emerged when these data were pooled separately for this outcome by the measures of maximum aerobic capacity (VO_2 max, ml/kg/min) (20,23,26,27,32,48,62,65,67,68,70) and the Six-Minute Walk Test (meters) (24,26–29,37). There was no clear effect on VO_2 max alone, but PRT had a significant moderate effect on the walk test (*WMD* 53.7 meters; 95% CI 27.0, 80.4), perhaps suggesting that the latter test provides a more relevant assessment of aerobic function in older people.

Table 2. Characteristics of Included Trials

Study	Number Included in Review*	Mean Age (y)**	Health and/or Functional Status	Exercise Intensity	Exercise Duration (wk)	Number of Exercises	Exercise Setting
Ades 1997 (67)	24	70	Healthy	High	12	4 UL, 3 LL	Gym
Baker 2001 (19)	46	68	Osteoarthritis	Moderate-high	16	5 LL (plus 2 functional exercises)	Home based
Balagopal 2001 (200)	20	71	Healthy	High	12	4 UL, 3 LL	Gym
Bermon 1999 (201)	32	70	Healthy	High	8	1 UL, 2 LL	Gym
Brandon 2000 (72)	85	72	Healthy	High	16	3 LL	Gym
Buchner 1997 (62)	55	74	Functional limitation	High	24–26	2 UL, 9 LL, 1 Tr	Gym
Castaneda 2001 (31)	26	65	Chronic renal insufficiency	High	12	2 UL, 3 LL	Gym
Chandler 1998 (37)	100	78	Functional limitation	Low-moderate	10	8 LL	Home
Charette 1991 (4)	27	69	Healthy	High	12	7 LL	Gym
Collier 1997 (202)	39	65–85 (range)	Healthy	High	10	5 UL, 2 LL	Gym
Damush 1999 (50)	71	68	Healthy	Low-moderate	8	4 UL, 3 LL	Gym
Donald 2000 (34)	58	81	Hospitalized	High	NR	2 LL	Hospital
Ettinger 1997 (20)	295	68	Osteoarthritis, functional limitation	Moderate-high	78	4 UL, 5 LL, 1 Tr	Gym + home
Fiatarone 1994 (36)	51	87	Frail	High	10	2 LL	Gym
Fiatarone 1997 (38)	34	82	Frail	High	16	11 (UL, LL)	Home
Flynn 1999 (51)	29	73	Healthy	High	10	8 LL	Gym
Hagerman 2000 (48)	22	64	Healthy	High	16	3 LL	Gym
Haykowsky 2000 (203)	22	68	Healthy	High	16	5 UL, 3 LL	Gym
Hennessey 2001 (204)	16	71	Frail	Moderate-high	25	11 (UL, LL)	Gym
Hiatt 1994 (23)	19	67	Peripheral arterial disease	High	12	6 LL	Gym
Hortobagyi 2001 (205)	30	72	Healthy	High + low	10	1 LL	Gym
Jette 1996 (58)	102	71	Healthy	Low-moderate	12–15	10 (UL, LL, Tr)	Home
Jette 1999 (39)	215	75	Functional limitation	Low-moderate	26	11 (UL, LL, Tr)	Home
Jones 1994 (53)	46	67	Healthy	Moderate	16	7 LL	Gym + home
Jubrias 2001 (206)	26	69	Healthy	High	24	1 LL, 2 UL	Gym
Judge 1994 (63)	55	80	Healthy	Moderate-high	12	6 LL	Gym
Kerr 2001 (207)	84	60	Healthy	High	104	4 UL, 4 LL	Gym
Latham 2001 (45)	20	81	Hospitalized	High	2	1 LL	Hospital
Latham 2003 (35)	243	79	Frail	Moderate-high	10	1 LL	Home
Maiorana 1997 (32)	31	60	3 Months post-CABG	Moderate-high	10	7 UL, 4 LL, 1 Tr	Gym
Maurer 1999 (21)	113	66	Osteoarthritis	High	8	1 LL	Gym
McCartney 1995 (64)	142	64	Healthy	High	42	3 UL, 3 LL, 1 Tr	Gym
McGuigan 2001 (24)	20	68	Peripheral arterial disease	High	24	UL, LL, Tr	Gym
McMurdo 1995 (40)	86	82	Functional limitation	Low-moderate	26	24 (UL, LL, Tr)	Home
Mihalko 1996 (44)	58	83	Healthy	High	8	5 UL	Gym
Moreland 2001 (25)	133	69	Stroke	NR	NR	NR	Hospital
Nelson 1994 (52)	40	61	Healthy	High	52	2 LL, 2 Tr	Gym
Newnham 1995 (41)	30	82	Functional limitation	High	12	UL, LL, Tr	Gym
Nichols 1993 (54)	36	67	Healthy	High	24	4 UL, 2 LL, 1 Tr	Gym
Parkhouse 2000 (30)	22	68	Low bone mineral density	High	32	9 LL	Gym
Perrig-Chiello 1998 (208)	46	73	Healthy	NR	8	NR	Gym
Pollock 1991 (65)	36	72	Healthy	High	26	5 UL, 2 LL, 3 Tr	Gym
Pu 2001 (26)	16	77	Heart failure	High	10	2 UL, 2 LL	Gym
Rall 1996 (209)	14	70	Healthy	High	12	1 UL, 2 LL, 2 Tr	Gym
Rhodes 2000 (55)	44	69	Healthy	High	52	3 UL, 3 LL	Gym
Sartorio 2001 (210)	30	73	Healthy	High	16	4 UL, 2 LL	Gym
Schilke 1996 (22)	20	65	Osteoarthritis	High	8	1 LL	Gym
Schlicht 1999 (71)	24	72	Healthy	High	8	6 LL	Gym
Simpson 1992 (28)	34	73	Chronic airflow limitation	High	8	1 UL, 2 LL	Gym
Singh 1997 (29)	32	71	Depressed	High	10	2 UL, 3 LL	Gym
Siplia 1996 (56)	27	77	Healthy	High	18	4 LL	Gym
Skelton 1995 (42)	47	80	Healthy	Low-moderate	12	3 UL, 6 LL	Gym + home
Skelton 1996 (59)	20	81	Functional limitation	Low-moderate	8	2 UL, 6 LL	Gym + home
Taaffe 1996 (57)	36	68	Healthy	High + low	52	3 LL	Gym
Taaffe 1999 (211)	46	71	Healthy	High	24	4 UL, 3 LL	Gym
Topp 1993 (60)	63	70	Healthy	Low-moderate	12	6 UL, 6 LL	Gym + home

Table 2. Characteristics of Included Trials (*Continued*)

Study	Number Included in Review*	Mean Age (y)**	Health and/or Functional Status	Exercise Intensity	Exercise Duration (wk)	Number of Exercises	Exercise Setting
Topp 1996 (61)	61	72	Healthy	Low-moderate	14	11 (UL, LL, Tr)	Home
Tsutsumi 1997 (70)	42	68	Healthy	High + low	12	7 UL, 2 LL, 2 Tr	Gym
Tyni-Lenne 2001 (212)	24	63	Heart failure	Low-moderate	8	Many UL, LL	Gym
Vincent 2002 (66)	62	68	Healthy	High	26	6 UL, 5 LL, 2 Tr	Gym
Westhoff 2000 (43)	26	76	Functional limitation	Low	10	9 LL	Gym + home
Wood 2001 (213)	16	45	Healthy	High	12	5 UL, 3 LL	Gym

Notes: *Number excludes trial groups that do not meet this review's inclusion criteria (i.e., aerobic training groups).

**When overall age not reported, mean age for PRT group reported.

UL = upper limb; LL = lower limb; Tr = trunk; NR = not reported; gym + home = program performed at both settings; high + low = different groups performed PRT at different intensities; PRT = progressive resistance training; CABG = coronary artery bypass graft.

Effects of PRT—Functional Limitation Measures

No clear effect was found for PRT on measures of standing balance (*SMD* 0.11; 95% CI –0.03, 0.25) among 789 participants (35,37,39,41–43,45,59,60,62,63,71). Similar effect estimates were found when only two measures (i.e., timed position-holding and balance during more complex activities such as the Berg Balance test) were examined separately (Table 3). However, for the chair-rise (i.e., the time to stand up from a sitting position), a significant, moderate-to-large beneficial effect of PRT was observed (*SMD* –0.67; 95% CI –1.31, –0.02), although this was derived from only a small amount of data ($n = 185$) (29,59,63,72). The two measures of walking speed used, gait speed (higher scores indicate faster mobility) and timed walk (i.e., time to walk a set distance, higher scores indicate slower mobility), were analyzed separately (Table 3). PRT showed a modest significant beneficial effect on gait speed ($n = 798$) with *WMD* 0.07 (95% CI 0.04, 0.09) meters per second (Figure 2) (27,29,35–37,41,42,56,60–63,71,72). Although a nonsignificant effect (*WMD* 0.77 s, 95% CI –0.65, 2.2; lower score indicates better performance) was found for the timed walk ($n = 81$), this was based on very limited data. When data for the Timed Up-and-Go Test (i.e., time to stand, walk 3 meters, turn, and return to sitting) were pooled ($n = 494$) (35,39,41,43,45,59), the estimate was consistent with either no effect or a small, nonsignificant benefit (*WMD* –1.2 s, 95% CI –2.8, 0.4; lower score indicates better performance).

Effects of PRT—Physical Disability Measures

A total of 14 trials reported disability outcomes. Two analyses were conducted for physical disability because 10 studies ($n = 722$) (19,23,25,29,34,35,37,50,62,70) used measures where higher scores indicated less disability (Figure 3), 6 studies ($n = 559$) (19,20,22,29,39,43) used measures where higher scores indicated greater disability,

Table 3. Summary of Main Results

Outcome	Number of Trials	Number of Participants	Heterogeneity (*p* Value)	Model	Effect Size (95% CI)	Effect Estimate (*p* Value)
Strength (leg extensors)	41	1955	<.0001	Random	*SMD* 0.68 (0.52, 0.84)	<.0001
Aerobic capacity						
Overall	16	777	.91	Fixed	*SMD* 0.13 (−0.02, 0.27)	.08
VO_2 maximum	11	496	1.0	Fixed	*WMD* 0.47 ml/kg/min (−0.03, 0.97)	.07
6-Minute walk test	6	212	.86	Fixed	*WMD* 53.7 m (27.0, 80.4)	<.0001
Balance						
Overall	12	789	.22	Fixed	*SMD* 0.11 (−0.03, 0.25)	.11
Timed Position Hold	5	187	.8	Fixed	*SMD* 0.16 (−0.13, 0.45)	.3
Complex Activities	7	602	.054	Random	*SMD* 0.19 (−.08, 0.46)	.17
Chair-rise	4	185	.0078	Random	*SMD* −0.67 (−1.31, –0.02)	.04
Gait speed						
Speed	14	798	.33	Fixed	*WMD* 0.07 m/s (0.04, 0.09)	<.0001
Timed walk*	4	81	.96	Fixed	*WMD* 0.77 s (−0.65, 2.2)	.3
Timed up-and-go*	6	494	.28	Fixed	*WMD* −1.2 s (−2.8, 0.4)	.13
Physical disability						
Higher score indicates less ability	10	722	.44	Fixed	*SMD* 0.01 (−0.14, 0.16)	.9
Lower score indicates less disability*	6	559	.0081	Random	*SMD* −0.17 (−0.53, 0.19)	.4
PF of SF-36	7	493	.2	Fixed	*WMD* 0.96 (−3.35, 5.26)	.7

Notes: *Lower score indicates better performance; otherwise, higher score indicates better performance.

CI = confidence interval; *SMD* = standardized mean difference; *WMD* = weighted mean difference; m = meters; s = seconds; m/s = meters per second; PF = physical function domain of the SF-36, range 0–100.

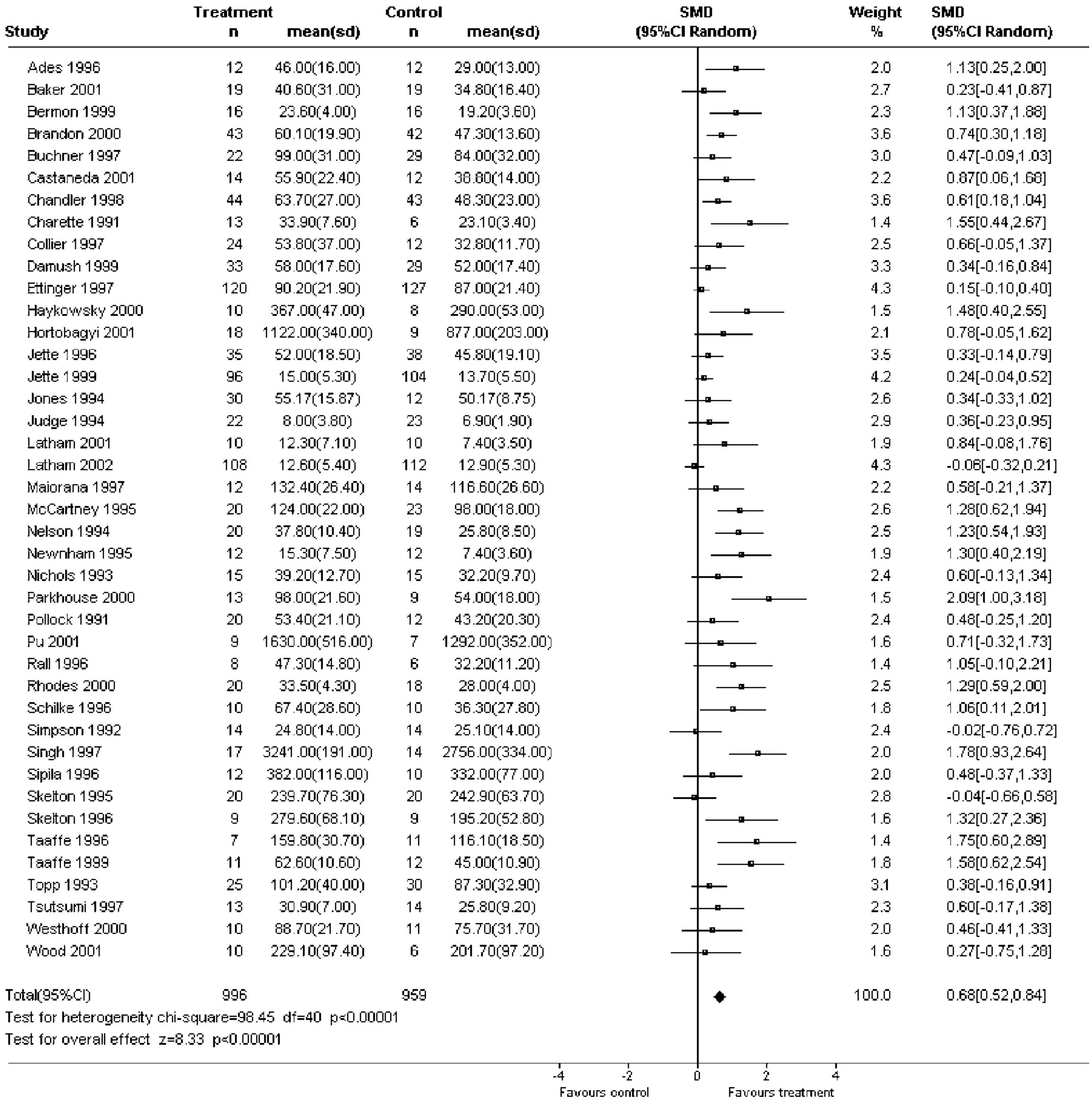

Figure 1. Forest plot of lower-limb strength.

and 2 studies that reported disability used both methods. There was no evidence that PRT had an effect on physical disability, either with the higher score reflecting better measures (*SMD* 0.01; 95% CI –0.14, 0.16) or the lower score reflecting better measures (*SMD* –0.17; 95% CI –0.53, 0.19). When HRQOL and ADL measures were examined separately, there was still no evidence of benefit of PRT. For example, when the PF domain of the SF-36 was pooled, a modest difference of less than 1 point on this 100-point scale was found between the two groups (*WMD* 0.96; 95% CI –3.35, 5.26).

Effects of PRT—Falls and Other Adverse Events

Only five studies investigated the effect of PRT on falls, but these data were not reported in a manner that allowed for pooling. Although Donald and colleagues (34) and three trials in the Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT) preplanned meta-analysis (36,62,63) showed a reduction in falls, the confidence intervals were wide around the risk reduction estimates. Thus, as most of the trials in this overview were small (i.e., $n < 60$), pooling would be unlikely to provide the power necessary to detect a modest effect on falls.

Thirty-two studies did not make any comment about adverse events or side effects associated with PRT. Of the 30 studies that did comment, 14 reported no adverse events and 16 reported some adverse reaction. An additional nine studies did not report adverse events as such, but it is likely that an event occurred, since these studies reported drop-outs from the exercise group secondary to increasing pain or specific injuries (4,21,37,38,48,49,58,60,73). Only 6 of 62 studies provided an a priori definition of an adverse event in the study methods or objectives (20,25,29,35,63,65). Five of these six studies detected adverse events (20,25,35,63,65).

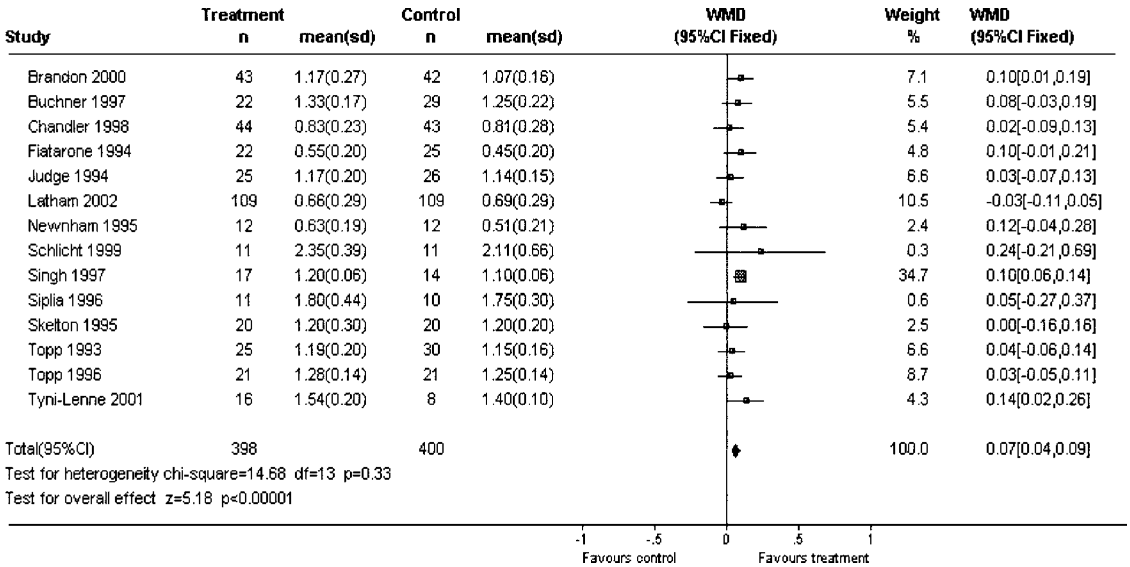

Figure 2. Forest plot of gait speed.

Most adverse events were musculoskeletal problems; there were no reports of cardiac events or death associated with PRT. Three studies provided data about use of health services (29,34,35). Two studies reported decreased rates of hospitalization and/or length of stay, while one reported an increased risk of hospitalization. Six studies provided data on participant deaths (20,25,34–36,41), with 10 deaths reported in the treatment group compared with 17 in the control group (odds ratio [OR] 0.58; 95% CI 0.27, 1.24). In at least two studies (37,64), the death of participants was reported, but these data could not be pooled because the participants' assigned group was not specified.

Exploratory Subgroup and Sensitivity Analyses

The large number of participants in this overview allowed sensitivity and subgroup analyses to be undertaken for the strength outcome. To explore the effect of methodological quality, data were stratified by use of factors known to affect a trial's internal validity. Effect estimates were lower in studies that used blinded assessors, concealed allocation, and intention-to-treat analyses (Table 4). The use of attention control groups did not affect the effect estimates. Subgroup analyses were also conducted to explore the impact of differences in the form of exercise program and types of participants. Both high- and low-moderate-intensity PRT had significant effects on strength, but the former method had a larger effect (Table 4). The duration of PRT program (i.e., greater than or less than 12 weeks) appeared to have little effect on outcome (Table 5). However, there was considerable statistical heterogeneity across these data. There was no difference in the treatment effect among participants who were healthy compared with those with specific health problems (Table 5). However, there was a reduced effect in trials that included people with a physical disability or functional limitation, but most of these programs were carried out at a low-to-moderate intensity (Table 5). Since there was considerable statistical heterogeneity in these data, caution should be exercised in their interpretation. Sensitivity analyses were conducted to determine whether the removal of one of the largest studies, the Frailty Interventions Trial in Elderly Subjects (FITNESS), would affect outcomes that were assessed in this trial. Excluding the FITNESS trial did not change the significance of strength, gait speed, overall physical disability, or physical disability as assessed by the PF domain of the SF-36. Excluding FITNESS did increase the effect estimates of balance and timed up-and-go measures so that they approached statistical significance, although the effect estimates were still small for both outcomes (balance: *SMD* 0.23, 95% CI 0.06, 0.39, $p = .07$; timed up-and-go: *WMD* −1.62 s, 95% CI −3.24, 0.01, $p = .05$).

Discussion

This review identified, graded, and synthesized the literature regarding the effect of a specific form of exercise, PRT, that is widely used in the rehabilitation of older people. Our systematic search strategy allowed the inclusion of trials of participants with a range of health problems, and evaluations of programs with varying intensity and method of delivery of PRT, which increased the external validity and generalizability of the data. We were able to provide an overall assessment of the effects of the intervention on clinically relevant outcomes in older people, based on the current evidence. PRT was found to have a large positive effect on strength, the most proximal measure of impairment, and a small-to-moderate positive effect on other aspects of impairment and functional limitation. However, we were unable to show that these effects of PRT translated into improvements in physical disability, and the data did not allow an adequate assessment of associated risks, although some adverse events, mainly musculoskeletal, were evident in many trials.

A major finding was the poor methodological quality of most of the 62 included studies. As most of the studies did

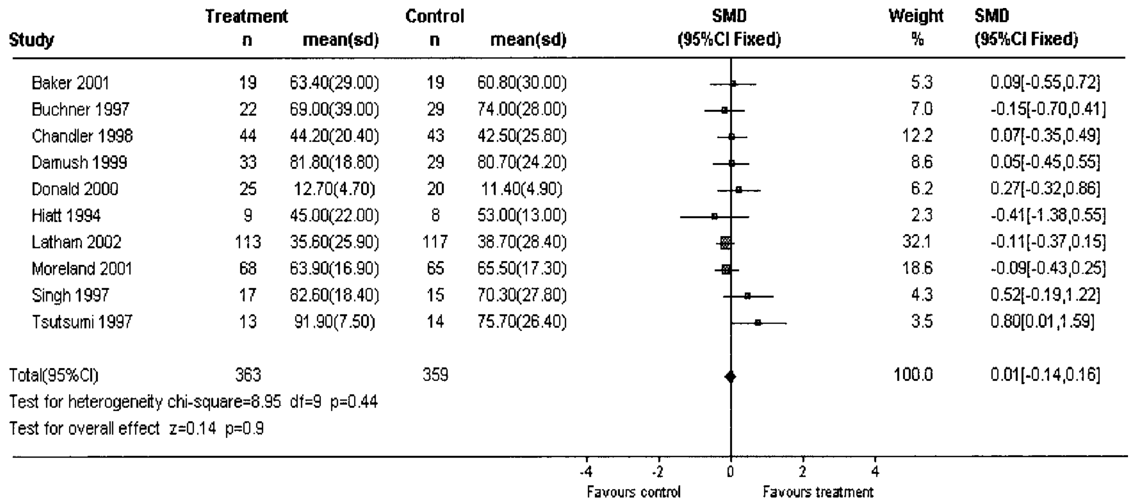

Figure 3. Forest plot of physical disability measures.

not use design features that are known to increase internal validity, such as intention-to-treat analysis, blinded outcome assessors, attention control groups, or concealed randomization, caution is required when drawing conclusions from these data. Our sensitivity analyses suggest that low-quality trials overestimate the effect of PRT; although higher quality trials continued to find a beneficial effect of PRT on strength, the effect size was considerably attenuated.

While PRT had a large positive effect on the strength of older people, there was significant statistical heterogeneity associated with this estimate, which was reduced but not entirely eliminated when the data were pooled separately for trials utilizing different participants, training doses and design features. In exploratory subgroup analyses, it appeared that intensity has the greatest effect, and duration, a much smaller effect, on strength. The small effect of duration could have been influenced by our choice of a cut-off point (12 weeks), since at least one half of strength gain in 1 year occurs during the first 12 weeks of training. The health status of the participants did not have a clear effect on the response to PRT, although it did appear that people with preexisting functional limitations had smaller gains in strength. However, these subgroup analyses must be treated with caution, as the number of participants available in these analyses was small, which decreases the precision of these estimates. In addition, it is possible that study quality is a confounder for some of these observed differences, as several of the largest and highest quality trials included people with function limitations and/or lower intensity training programs. We chose not to perform meta-regression analyses, as these can be problematic since there are many characteristics that could be investigated but usually only a small number of trials (74). This can lead to data dredging, and false-positive results may occur, which can be misleading for both clinical practice and future research (75).

Adverse events were poorly monitored and reported in most of these trials, making it difficult to assess the risk of injury or other events associated with resistance training. The finding that several studies reported dropouts from the exercise program due to pain or injury, yet failed to report any adverse events, suggests that adverse events might have been under-reported in trials. This hypothesis is also supported by the finding that events were more likely to be reported in studies with a clear definition of adverse events than in those with no definition. Furthermore, the large number of dropouts from PRT also raises the possibility that people left the trials because they experienced adverse effects. However, it is reassuring that there was no evidence of an increased risk of hospitalization or death, and several studies reported decreased use of health

Table 4. Sensitivity Analyses of the Effect of Study Quality on Lower Limb Strength

Group		Number of Trials	Number of Participants	Heterogeneity (*p* Value)	Model	Effect Size (95% CI)	Overall Effect on Strength (*p* Value)
Blinded assessors	Yes	10	1010	.098	Random	*SMD* 0.29 (0.12, 0.47)	.001
	No	31	945	.01	Random	*SMD* 0.83 (0.64, 1.01)	<.0001
Concealed randomization	Yes	9	570	.031	Random	*SMD* 0.38 (0.07, 0.70)	.02
	No	32	1385	.0003	Random	*SMD* 0.78 (0.60, 0.96)	<.0001
Intention-to-treat analysis	Yes	7	656	.025	Random	*SMD* 0.33 (0.05, 0.61)	.02
	No	34	1299	.0012	Random	*SMD* 0.76 (0.59, 0.93)	<.0001
Attention control	Yes	12	830	<.0001	Random	*SMD* 0.63 (0.31, 0.94)	<.0001
	No	29	1125	.013	Random	*SMD* 0.70 (0.52, 0.87)	<.0001

Note: CI = confidence interval; *SMD* = standardized mean difference.

Table 5. Subgroup Analysis of the Effect of Exercise Dose and Participant Characteristics on Lower Limb Strength

Group	Number of Trials	Number of Participants	Heterogeneity (*p* Value)	Model	Effect Size (95% CI)	Overall Effect on Strength (*p* Value)
Exercise dose						
High intensity	32	1357	<.0001	Random	*SMD* 0.81 (0.60, 1.01)	<.0001
Low intensity	9	598	.54	Fixed	*SMD* 0.34 (0.18, 0.51)	<.0001
Short duration (≤12 weeks)	25	1007	.0015	Random	*SMD* 0.62 (0.42, 0.82)	<.0001
Longer duration (<12 weeks)	16	948	<.0001	Random	*SMD* 0.77 (0.50, 1.05)	<.0001
Participant characteristics						
Specific health problem						
Yes	15	1016	.029	Random	*SMD* 0.69 (0.51, 0.86)	<.0001
No	26	939	<.0001	Random	*SMD* 0.69 (0.51, 0.86)	<.0001
Functional limitations						
Yes	9	871	.017	Random	*SMD* 0.36 (0.11, 0.60)	.004
No	32	1084	.0064	Random	*SMD* 0.76 (0.59, 0.94)	<.0001

Note: CI = confidence interval; *SMD* = standardized mean difference.

care services in the PRT group. In addition, there were no reports of serious adverse events (i.e., death or illness resulting in hospitalization) associated with PRT. Unfortunately, the sparse data did not allow an adequate assessment of the effect of PRT on fall risk.

To address these issues, it is imperative that future trials of PRT in older people utilize rigorous designs that minimize bias, recruit an adequate number of participants, assess substantive outcomes such as disability, and carefully monitor adverse events. Well-designed trials are also required to determine the most appropriate dose to use (i.e., high intensity compared with low intensity) with different participants, particularly people with preexisting functional limitations and disability, and in different settings (i.e., home based versus gym based). New data, obtained from newly identified trials or provided by authors of currently included trials, will be incorporated in updates of the full review of this topic, which is part of the Cochrane Collaboration.

A systematic and quantitative synthesis of the effectiveness of PRT has shown that it increases strength and has a positive effect on several important functional limitations in older people. However, based on current data, there is no evidence that PRT alone has an effect on physical disability. It is possible that, to impact at this higher level of functioning, PRT needs to be combined with other forms of exercise (e.g., balance training) and that more consideration needs to be given to other factors that contribute to disability such as self-efficacy, motivation, or barriers to participation. Because of uncertainty about the risk of adverse effects associated with PRT, some caution appears warranted in utilizing this intervention in widespread clinical practice, particularly in unsupervised high-intensity programs for people who could potentially be at higher risk of injury. Thus, clinicians should monitor for adverse effects in older people undertaking PRT, particularly in older people who are frail or have been ill recently. However, when assessing the risks and benefits of PRT, it is important to note that inactivity also has serious negative consequences for older people. In summary, PRT shows promise in improving some important functional limitations in older people, but current evidence does not indicate that these changes are sufficient to improve older people's level of physical disability.

Acknowledgements

This review was conducted under the auspices of the Cochrane Musculoskeletal Injuries Group of the Cochrane Collaboration. We thank this review group and the editors for their support and input. In particular, the authors thank Lesley Gillespie and LeeAnn Morton for their assistance with searches of specialized registers and development of the search strategies.

Address correspondence to Nancy K. Latham, PhD, PT, Center for Rehabilitation Effectiveness, Sargent College of Health and Rehabilitation Sciences, Boston University, 635 Commonwealth Avenue, Boston, MA 02215. E-mail: nlatham@bu.edu

References

1. Buchner DM, Larson EB, Wagner EH, Koepsell TD, De Lateur BJ. Evidence for a non-linear relationship between leg strength and gait speed. *Age Ageing*. 1996;25:386–391.
2. Guralnik JM, Ferrucci L, Simonsick EM, Salive ME, Wallace RB. 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.
3. Tinetti ME, Williams TF, Mayewski R. Fall risk index for elderly patients based on number of chronic disabilities. *Am J Med*. 1986;80:429–434.
4. Charette SL, McEvoy L, Pyka G, et al. Muscle hypertrophy response to resistance training in older women. *J Appl Physiol*. 1991;70:1912–1916.
5. ACSM. American College of Sports Medicine Position Stand. The recommended quantity and quality of exercise for developing and maintaining cardio-respiratory and muscular fitness, and flexibility in adults. *Med Sci Sports Exerc*. 1998;30:975–991.
6. Fiatarone Singh MA. Exercise comes of age: rationale and recommendations for a geriatric exercise prescription. *J Gerontol Med Sci*. 2002;57A:M262–M282.
7. Keysor JJ, Jette AM. Have we oversold the benefit of late-life exercise? *J Gerontol Med Sci*. 2001;56A:M412–M423.
8. Nagi S. Disability concepts revisited: implications for prevention. In: Tarlov AR, ed. *Disability in America*. Washington, DC: National Academy Press; 1991.
9. World Health Organization. *International Classification of Functioning, Disability and Handicap (ICF)*. Geneva: World Health Organization; 2001.
10. Mahoney FI, Barthel DW. Functional evaluation: the Barthel index. *Md State Med J*. 1965;14:61–65.

11. Ware J. *SF-36 Health Survey—Manual and Interpretation Guide*. Boston: The Health Institute, New England Medical Center; 1993.
12. *Metaview 4.1* [computer program]. Version 4.1: Update Software; 1999.
13. Hedges LV, Olkin I. *Statistical Methods for Meta-analysis*. San Diego, CA: Academic Press; 1985.
14. DerSimonian R, Laird N. Meta-analysis in clinical trials. *Controlled Clin Trials*. 1986;7:177–188.
15. Ballor DL, Harvey-Berino JR, Ades PA, Cryan J, Calles-Escandon J. Contrasting effects of resistance and aerobic training on body composition and metabolism after diet-induced weight-loss. *Metabolism*. 1996;45:179–183.
16. Earles DR, Judge JO, Gunnarsson OT. Velocity training induces power-specific adaptations in highly functioning older adults. *Arch Phys Med Rehabil*. 2001;82:872–878.
17. Hepple RT, Mackinnon SL, Goodman JM, Thomas SG, Plyley MJ. Resistance and aerobic training in older men: effects on VO2peak and the capillary supply to skeletal muscle. *J Appl Physiol*. 1997;82:1305–1310.
18. Hunter GS, Treuth MS, Weinsier RL, et al. The effects of strength conditioning on older women's ability to perform daily tasks. *J Am Geriatr Soc*. 1995;43:756–760.
19. Baker KR, Nelson ME, Felson DT, Layne JE, Sarno R, Roubenoff R. The efficacy of home based progressive strength training in older adults with knee osteoarthritis: a randomized controlled trial. *J Rheumatol*. 2001;28:1655–1665.
20. Ettinger Jr WH, Burns R, Messier SP, et al. A randomized trial comparing aerobic exercise and resistance exercise with a health education program in older adults with knee osteoarthritis. The Fitness Arthritis and Seniors Trial (FAST). *JAMA*. 1997;277:25–31.
21. Maurer BT, Stern AG, Kinossian B, Cook KD, Schumacher HR. Osteoarthritis of the knee: isokinetic quadriceps exercise versus an educational intervention. *Arch Phys Med Rehabil*. 1999;80:1293–1299.
22. Schilke JM, Johnson GO, Housh TJ, O'Dell JR. Effects of muscle-strength training on the functional status of patients with osteoarthritis of the knee joint. *Nurs Res*. 1996;45:68–72.
23. Hiatt W, Wolfel E, Meier R, Regensteiner J. Superiority of treadmill walking exercise versus strength training for patients with peripheral arterial disease. *Circulation*. 1994;90:1866–1874.
24. McGuigan MRM, Bronks R, Newton RU, et al. Resistance training in patients with peripheral arterial disease: effects on myosin isoforms, fiber type distribution and capillary supply to skeletal muscle. *J Gerontol Biol Sci*. 2001;56A:B302–B310.
25. Moreland J. Resistance training post-stroke. Personal Communication, 2001.
26. Pu CT, Johnson MT, Forman DE, et al. Randomized trial of progressive resistance training to counteract the myopathy of chronic heart failure. *J Appl Physiol*. 2001;90:2341–2350.
27. Tyni-Lenne R, Gordon A, Jensen-Urstad M, Kencker K, Jansson E, Sylven C. Aerobic training involving a minor muscle mass shows greater efficiency than training involving a major muscle mass in chronic heart failure patients. *J Cardiac Fail*. 1999;5:300–307.
28. Simpson K, Killian K, McCartney N, Stubbing DG, Jones NL. Randomised controlled trial of weightlifting exercise in patients with chronic airflow limitation. *Thorax*. 1992;47:70–75.
29. Singh NA, Clements KM, Fiatarone MA. A randomized controlled trial of progressive resistance training in depressed elders. *J Gerontol Med Sci*. 1997;52A:M27–M35.
30. Parkhouse WS, Coupland DC, Li C, Vanderhoek KJ. IGF-1 bioavailability is increased by resistance training in older women with low bone mineral density. *Mech Ageing Devel*. 2000;113:75–83.
31. Castaneda C, Gordon PL, Uhlin KL, et al. Resistance training to counteract the catabolism of a low-protein diet in patients with chronic renal insufficiency. A randomized, controlled trial [Comment]. *Ann Intern Med*. 2001;135:965–976.
32. Maiorana AJ, Briffa TG, Goodman C, Hung J. A controlled trial of circuit weight training on aerobic capacity and myocardial oxygen demand in men after coronary artery bypass surgery. *J Cardiopulm Rehabil*. 1997;17:239–247.
33. Hennessey JV, Chromiak JA, Della Ventura S, et al. Growth hormone administration and exercise effects on muscle fiber type and diameter in moderately frail older people. *J Am Geriatr Soc*. 2001;49:852–858.
34. Donald IP, Pitt K, Armstrong E, Shuttleworth H. Preventing falls on an elderly care rehabilitation ward. *Clin Rehabil*. 2000;14:178–185.
35. Latham NK, Anderson CS, Lee A, Bennett D, Moseley AM, Cameron ID. A randomized controlled trial of quadriceps resistance exercise and vitamin D in hospitalized frail older people: The Frailty Interventions Trial in Elderly Subjects (FITNESS). *J Am Geriatr Soc*. 2003;51:291–301.
36. Fiatarone MA, O'Neill EF, Doyle Ryan N, et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. *N Engl J Med*. 1994;330:1769–1775.
37. 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.
38. Fiatarone MA, O'Neil EF, Doyle Ryan N, Clements K. Efficacy of home-based resistance training in frail elders. In: Andrews GR, ed. *Abstracts of the 16th Congress of the International Association of Gerontology*. Bedford Park, South Australia: 1997 World Congress of Gerontology, Inc.; p 323, abstract 985.
39. Jette AM, Lachman M, Giorgetti MM, et al. Exercise—It's never too late: the Strong-for-Life Program. *Am J Publ Health*. 1999;89:66–72.
40. McMurdo ME, Johnstone R. A randomized controlled trial of a home exercise programme for elderly people with poor mobility. *Age Ageing*. 1995;24:425–428.
41. Newnham J. The effects of a strengthening program on muscle function and mobility skills in an elderly institutionalized population [MSc Thesis]. Montreal: McGill University; 1995.
42. Skelton DA, Young A, Greig CA, Malbut KE. Effects of resistance training on strength, power, and functional abilities of women aged 75 and older. *J Am Geriatr Soc*. 1995;41:1081–1087.
43. Westhoff MH, Stemmerik L, Boshuizen HC. Effects of a low-intensity strength-training program on knee-extensor strength and functional ability of frail older people. *J Aging Phys Activ*. 2000;8:325–342.
44. Mihalko SL, McAuley E. Strength training effects on subjective well-being and physical function in the elderly. *J Aging Phys Activ*. 1996;4:56–68.
45. Latham NK, Stretton C, Ronald M. Progressive resistance strength training in hospitalised older people: a preliminary investigation. *NZ J Physiother*. 2001;29:41–48.
46. Sartorio A, Lafortuna C, Capodaglio P, Vangeli V, Narici MV, Faglia G. Effects of a 16-week progressive high-intensity strength training (HIST) on indexes of bone turnover in men over 65 years: a randomized controlled study. *J Endocrinol Invest*. 2001;24:882–886.
47. Haykowsky M, Humen D, Teo K, et al. Effects of 16 weeks of resistance training on left ventricular morphology and systolic function in healthy men >60 years of age. *Am J Cardiol*. 2000;85:1002–1006.
48. Hagerman FC, Walsh SJ, Staron RS, et al. Effects of high-intensity resistance strength training on untrained older men I. Strength, cardiovascular and metabolic responses. *J Gerontol Biol Sci*. 2000;55A:B336–B346.
49. Kerr D, Ackland T, Maslen B, Morton A, Prince RL. Resistance training over 2 years increases bone mass in calcium-replete postmenopausal women. *J Bone Miner Res*. 2001;16:175–181.
50. Damush TM, Damush JGJ. The effects of strength training on strength and health-related quality of life in older adult women. *Gerontologist*. 1999;39:705–710.
51. Flynn MG, Fahlman M, Braun WA, et al. Effects of resistance training on selected indexes of immune function in elderly women. *J Appl Physiol*. 1999;86:1905–1913.
52. Nelson ME, Fiatarone MA, Morganti CM, Trice I, Greenberg RA, Evans WJ. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures: a randomized controlled trial. *JAMA*. 1994;272:1909–1914.
53. Jones CJ, Rikli RE, Benedict J, Williams P. Effects of a resistance training program on leg strength and muscular endurance of older women. *J Aging Phys Activity*. 1994;2:182–195.
54. Nichols JF, Omizo DK, Peterson KK, Nelson KP. Efficacy of heavy-resistance training for active women over sixty: muscular strength, body composition and program adherence. *J Am Geriatr Soc*. 1993;41:205–210.
55. Rhodes EC, Martin AD, Taunton JE, Donnelly M, Warren J, Elliot J. Effects of one year of resistance training on the relation between

muscular strength and bone density in elderly women. *Br J Sports Med*. 2000;34:18–22.
56. Sipila S, Multanen J, Kallinen M, Era P, Suominen H. Effects of strength and endurance training on isometric muscle strength and walking speed in elderly women. *Acta Physiol Scand*. 1996;156:457–464.
57. Taaffe DR, Pruitt L, Pyka G, Guido D, Marcus R. 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.
58. Jette AM, Harris BA, Sleeper L, et al. A home-based exercise program for nondisabled older adults. *J Am Geriatr Soc*. 1996;44:644–649.
59. Skelton DA, McLaughlin AW. Training functional ability in old age. *Physiother*. 1996;82:159–167.
60. Topp R, Mikesky A, Wigglesworth J, Holt W, Edwards JE. The effect of a 12-week dynamic resistance strength training program on gait velocity and balance in older adults. *Gerontologist*. 1993;33:501–506.
61. Topp R, Mikesky A, Dayhoff N, Holt W. Effect of resistance training on strength, postural control, and gait velocity in older adults. *Clin Nurs Res*. 1996;5:407–421.
62. 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 Med Sci*. 1997;52A:M218–M224.
63. Judge JO, Whipple RH, Wolfson LI. Effects of resistance and balance exercises on isokinetic strength in older persons. *J Am Geriatr Soc*. 1994;42:937–946.
64. McCartney N, Hicks AL, Martin J, Webber CE. Long-term resistance training in elderly: effects on dynamic strength, exercise capacity, muscle, and bone. *J Gerontol Biol Sci*. 1995;50A:B97–B104.
65. Pollock ML, Carroll JF, Graves JE, et al. Injuries and adherence to walk/jog and resistance training programs in the elderly. *Med Sci Sports Exerc*. 1991;23:1194–1200.
66. Vincent KR, Braith RW. Resistance exercise and bone turnover in elderly men and women. *Med Sci Sports Exerc*. 2002;34:17–23.
67. Ades PA, Ballor DL, Ashikaga T, Utton JL, Nair KS. Weight training improves walking endurance in healthy elderly persons. *Ann Intern Med*. 1996;124:568–572.
68. Rall LC, Meydani SN, Kehayias JJ, Dawson Hughes B, Roubenoff R. The effect of progressive resistance training in rheumatoid arthritis. *Arthrit Rheum*. 1996;39:415–426.
69. Tsutsumi T, Don BM, Zaichkowsky LD, Delizonna LL. Physical fitness and psychological benefits of strength training in community dwelling older adults. *Appl Hum Sci*. 1997;16:257–266.
70. Tsutsumi T. The effects of strength training on mood, self-efficacy, cardiovascular reactivity and quality of life in older adults [PhD Dissertation]. Ann Arbor: University of Michigan; 1997.
71. Schlicht J, Camaione DN, Owen SV. Effect of intense strength training on standing balance, walking speed and sit-to-stand performance in older adults. *J Gerontol Med Sci*. 2001;56A:M281–M286.
72. Brandon LJ, Boyette LW, Gaasch DA, Lloyd DG. Effects of lower extremity strength training on functional mobility in older adults. *J Aging Phys Activ*. 2000;8:214–227.
73. Hortobagyi T, Tunnel D, Moody J, Beam S, DeVita P. Low- or high-intensity strength training partially restores impaired quadriceps force accuracy and steadiness in aged adults. *J Gerontol Biol Sci*. 2001;56A:B38–B47.
74. Higgins J, Thompson S, Deeks J, Altman D. Statistical heterogeneity in systematic reviews of clinical trials: a critical appraisal of guidelines and practice. *J Health Serv Res Policy*. 2002;7:51–61.
75. Thompson SG, Higgins JPT. How should meta-regression analysis be undertaken and interpreted? *Stat Med*. 2002;21:1559–1573.
76. Adami S, Gatti D, Braga V, Bianchini D, Rossini M. Site-specific effects of strength training on bone structure and geometry of ultradistal radius in postmenopausal women. *J Bone Miner Res*. 1999;14:120–124.
77. Agre JC, Pierce LE, Raab DM, McAdams M, Smith EL. Light resistance and stretching exercise in elderly women: effect upon strength. *Arch Phys Med Rehabil*. 1988;69:273–276.
78. Aniansson A, Grimby G, Rundgren A, Svanborg A, Orlander J. Physical training in old men. *Age Ageing*. 1980;9:186–187.
79. Aniansson A, Gustafsson E. Physical training in elderly men with special reference to quadriceps muscle strength and morphology. *Clin Physiol*. 1981;1:87–98.
80. Aniansson A, Ljungberg P, Rundgren A, Wetterqvist H. Effect of a training programme for pensioners on condition and muscular strength. *Arch Gerontol Geriatr*. 1984;3:229–241.
81. Berg WP, Lapp BA. The effect of a practical resistance training intervention on mobility in independent, community-dwelling older adults. *J Aging Phys Activity*. 1998;6:18–35.
82. Brill P, Matthews M, Mason J, Davis D, Mustafa T, Macera C. Improving functional performance through a group-based free weight strength training program in residents of two assisted living communities. *Phys Occup Ther Geriatr*. 1998;15:57–69.
83. Brill PA, Probst JC, Greenhouse DL, Schell B, Macera CA. Clinical Feasibility of a free-weight strength-training program for older adults. *J Am Board Fam Pract*. 1998;11:445–451.
84. Brown AB, McCartney N, Sale DG. Positive adaptations to weight-lifting in the elderly. *J Appl Physiol*. 1990;69:1725–1733.
85. Chapman EA, DeVries HA, Swezey R. Joint stiffness: effects of exercise on young and old men. *J Gerontol*. 1972;27:218–221.
86. Connelly DM, Vandervoort AA. Improvement in knee extensor strength of institutionalized elderly women after exercise with ankle weights. *Physiother Canada*. 1995;47:15–23.
87. Connelly DM, Vandervoort AA. Effects of detraining on knee extensor strength and functional mobility in a group of elderly women. *J Orthop Sports Phys Ther*. 1997;26:340–346.
88. Connelly DM, Vandervoot AA. Effects of isokinetic strength training on concentric and eccentric torque development in the ankle dorsiflexors of older adults. *J Gerontol Biol Sci*. 2000;55A:B465–B472.
89. Cress ME, Thomas DP, Johnson J, et al. Effect of training on VO2 max, thigh strength and muscle morphology in septuagenarian women. *Med Sci Sports Exerc*. 1991;23:752–758.
90. Dupler TL, Cortes C. Effects of a whole-body resistive training regimen in the elderly. *Gerontology*. 1993;39:314–319.
91. Fiatarone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA, Evans WJ. High-intensity strength training in nonagenarians. Effects on skeletal muscle. *JAMA*. 1990;263:3029–3034.
92. Fisher NM, Pendergast DR, Calkins E. Muscle rehabilitation in impaired elderly nursing home residents. *Arch Phys Med Rehabil*. 1991;72:181–185.
93. 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;72:367–374.
94. Fisher NM, Gresham G, Pendergast DR. Effects of a quantitative progressive rehabilitation program applied unilaterally to the osteoarthritic knee. *Arch Phys Med Rehabil*. 1993;74:1319–1326.
95. 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;74:840–847.
96. Fisher NM, Kame VD, Jr., Rouse L, Pendergast DR. Quantitative evaluation of a home exercise program on muscle and functional capacity of patients with osteoarthritis. *Am J Phys Med Rehabil*. 1994;73:413–420.
97. Fisher NM, Pendergast DR. Effects of a muscle exercise program on exercise capacity in subjects with osteoarthritis. *Arch Phys Med Rehabil*. 1994;75:792–797.
98. Fisher NM, White SC, Yack HJ, Smolinski RJ, Pendergast DR. Muscle function and gait in patients with knee osteoarthritis before and after muscle rehabilitation. *Disability Rehabil*. 1997;19:47–55.
99. Frontera WR, Meredith C, O'Reilly KP, Knuttgen HG, Evans W. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J Appl Physiol*. 1988;64:1038–1044.
100. Frontera WR, Meredith CN, O'Reilly KP, Evans WJ. Strength training and determinants of VO2max in older men. *J Appl Physiol*. 1990;68:329–333.
101. Grimby G, Aniansson A, Hedberg M, Henning GB, Grangard U, Kvist H. Training can improve muscle strength and endurance in 78- to 84-yr-old men. *J Appl Physiol*. 1992;73:2517–2523.

102. Hakkinen K, Hakkinen A. Neuromuscular adaptations during intensive strength training in middle-aged and elderly males and females. *Electromyograph Clin Neurophysiol.* 1995;35:137–147.
103. Hakkinen K, Kallinen M, Linnamo V, Pastinen U-M, Newton R, Kraemer W. Neuromuscular adaptations during bilateral versus unilateral strength training in middle-aged and elderly men and women. *Acta Physiol Scand.* 1996;158:77–88.
104. Hartard M, Haber P, Ilieva D, Preisinger E, Seidl G, Huber J. Systematic strength training as a model of therapeutic intervention. A controlled trial in postmenopausal women with osteopenia. *Am J Phys Med Rehabil.* 1996;75:21–28.
105. Hurley M, Scott D. Improvements in quadriceps sensorimotor function and disability in patients with knee osteoarthritis following a clinically practicable exercise regime. *Br J Rheumatol.* 1998;37:1181–1187.
106. Ivey F, Tracy B, Lemmer J, et al. Effects of strength training and detraining on muscle quality: age and gender comparisons. *J Gerontol Biol Sci.* 2000;55A:B152–B157.
107. Kauffman TL. Strength training effect in young and aged women. *Arch Phys Med Rehabil.* 1985;66:223–226.
108. Kauranen K, Siira P, Vanharanta H. A 10-week strength training program: effect on the motor performance of an unimpaired upper extremity. *Arch Phys Med Rehabil.* 1998;79:925–930.
109. Larsson L. Physical training effects on muscle morphology in sedentary males at different ages. *Med Sci Sports Exerc.* 1982;14: 203–206.
110. Lexell J, Robertsson E, Stenstrom E. Effects of strength training in elderly women [letter]. *J Am Geriatr Soc.* 1992;40:190–191.
111. Lexell J, Downham DY, Larsson Y, Bruhn E, Morsing B. Heavy-resistance training in older Scandinavian men and women: short- and long-term effects on arm and leg muscles. *Scand J Med Sci Sports.* 1995;5:329–341.
112. Martel GF, Hurlbut DE, Lott ME, et al. Strength training normalises resting blood pressure in 65- to 73-year-old men and women with high blood pressure. *J Am Geriatr Soc.* 1999;47:1215–1221.
113. Meredith CN, Frontera WR, O'Reilly KP, Evans WJ. Body composition in elderly men: effect of dietary modification during strength training. *J Am Geriatr Soc.* 1992;40:155–162.
114. McCool JF, Schneider JK. Home-based leg strengthening for older adults initiated through private practice. *Prev Med.* 1991;28:105–110.
115. Moritani T, DeVries HA. Potential for gross muscle hypertrophy in older men. *J Gerontol.* 1980;35:672–682.
116. Parsons D, Foster V, Harman F, Dickinson A, Olivia P, Westerlind K. Balance and strength changes in elderly subjects after heavy resistance strength training [Abstract]. *Med Sci Sports Ex.* 1992;24(Suppl 5):S21.
117. Richards D. Efficacy of upper extremity strength training on upper extremity functional performance among elderly long-term care residents [PhD Dissertation]. Pittsburgh: University of Pittsburgh; 1996.
118. Roman WJ, Fleckenstein J, Stray-Gundersen J, Alway SE, Peshock R, Gonyea WJ. Adaptations in the elbow flexors of elderly males after heavy-resistance training. *J Appl Physiol.* 1993;74:750–754.
119. Ryan AS, Treuth MS, Hunter GR, Elahi D. Resistive training maintains bone mineral density in postmenopausal women. *Calcif Tissue Int.* 1998;62:295–299.
120. Sanders S. The effects of two modes of strength training on elderly men [PhD Dissertation]. Minneapolis, MN: Walden University; 1998.
121. Sashika H, Yoshiko M, Watanabe Y. Home program of physical therapy: effect on disabilities of patients with total hip arthroplasty. *Arch Phys Med Rehabil.* 1996;77:273–277.
122. Sharp SA, Brouwer BJ. Isokinetic strength training of the hemiparetic knee: effects on function and spasticity. *Arch Phys Med Rehabil.* 1997;78:1231–1236.
123. Shaw JM, Snow CM. Weighted vest exercise improves indices of fall risk in older women. *J Gerontol Med Sci.* 1998;53A:M53–M58.
124. Sipila S, Suominen H. Knee extension strength and walking speed in relation to quadriceps muscle composition and training in elderly women. *Clin Physiol.* 1994;14:433–442.
125. Sullivan DH, Wall PT, Bariola JR, Bopp MM, Frost YM. Progressive resistance muscle strength training of hospitalized frail elderly. *Am J Phys Med Rehabil.* 2001;80:503–509.
126. Taaffe DR, Marcus R. Dynamic muscle strength alterations to detraining and retraining in elderly men. *Clin Physiol.* 1997;17:311–324.
127. Treuth MS, Ryan AS, Pratley RE, et al. Effects of strength training on total and regional body composition in older men. *J Appl Physiol.* 1994;77:614–620.
128. Welsh L, Rutherford OM. Effects of isometric strength training on quadriceps muscle properties in over 55 year olds. *Eur J Appl Physiol.* 1996;72:219–223.
129. Adams KJ, Swank AM, Berning JM, Sevene-Adams PG, Barnard KL, Shimp-Bowerman J. Progressive strength training in sedentary, older African American women. *Med Sci Sports Exerc.* 2001;33:1567–1576.
130. Beniamini Y, Rubenstein JJ, Faigenbaum AD, Lichenstein AH, Crim MC. High-intensity strength training of patients enrolled in an outpatient cardiac rehabilitation program. *J Cardiopulm Rehabil.* 1999;19:8–17.
131. Beniamini Y, Rubenstein JJ, Zaichkowsky LD, Crim MC. Effects of high-intensity strength training on quality-of-life parameters in cardiac rehabilitation patients. *Am J Cardiol.* 1997;80:841–846.
132. Bilodeau M, Keen DA, Sweeney PJ, Shields RW, Enoka RM. Strength training can improve steadiness in persons with essential tremor. *Muscle Nerve.* 2000;23:771–778.
133. Chaloupka V, Elbl L, Nehyba S. Resistance training in patients after myocardial infarction (Silovy trenink u nemocnych po infarktu myokardu). *Vnitr Lek.* 2000;46:829–834.
134. Hakkinen A, Sokka T, Kotaniemi A, et al. Dynamic strength training in patients with early rheumatoid arthritis increases muscle strength but not bone mineral density. *J Rheumatol.* 1999;26:1257–1263.
135. Humphries B, Newton RU, Bronks R, et al. Effect of exercise intensity on bone density, strength, and calcium turnover in older women. *Med Sci Sports Exerc.* 2000;32:1043–1050.
136. Jones DA, Rutherford OM. Human muscle strength training: The effects of three different regimes and the nature of the resultant changes. *J Physiol.* 1987;391:1–11.
137. Kerr D, Morton A, Dick I, Prince R. Exercise effects on bone mass in postmenopausal women are site-specific and load-dependent. *J Bone Mineral Res.* 1996;11:218–225.
138. Komatireddy GR, Leitch RW, Cella K, Browning G, Minor M. Efficacy of low load resistive muscle training in patients with rheumatoid arthritis functional class II and III. *J Rheumatol.* 1997;24: 1531–1539.
139. Lohman T, Going S, Pamenter R, et al. Effects of resistance training on regional and total bone mineral density in premenopausal women: a randomized prospective study. *J Bone Miner Res.* 1995;10:1015–1024.
140. Maddalozzo GF, Snow CM. High intensity resistance training: effects on bone in older men and women. *Calcif Tissue Int.* 2000;66:399–404.
141. Magnusson G, Gordon A, Kaijser L, et al. High intensity knee extensor training in patients with heart failure. *Eur Heart J.* 1996;17: 1048–1055.
142. Narici MV, Roi GS, Landoni L, Minetti AE, Cerretelli P. Changes in force, cross-sectional area and neural activation during strength training and detraining of the human quadriceps. *Eur J Appl Physiol.* 1989;59:310–319.
143. Sinaki M, Wahner HW, Bergstralh EJ, et al. Three-year controlled, randomized trial of the effect of dose-specified loading and strengthening exercises on bone mineral density of spine and femur in nonathletic, physically active women. *Bone.* 1996;19:233–244.
144. Morris JN, Fiatarone M, Kiely DK, et al. Nursing rehabilitation and exercise strategies in the nursing home. *J Gerontol Med Sci.* 1999; 54A:M494–M500.
145. Allen A, Simpson JM. A primary care based fall prevention programme. *Physiother Theory Pract.* 1999;15:121–133.
146. Bernard S, Whittom F, Leblanc P, et al. Aerobic and strength training in patients with chronic obstructive pulmonary disease. *Am J Respir Care Crit Care Med.* 1999;159:896–901.
147. Brown M, Holloszy JO. Effects of a low intensity exercise program on selected physical performance characteristics of 60- to 70-years olds. *Ageing.* 1991;3:129–139.
148. Brown M, Sinacore DR, Ehsani AA, Binder EF, Holloszy JO, Kohrt WM. Low-intensity exercise as a modifier of physical frailty in older adults. *Arch Phys Med Rehabil.* 2000;81:960–965.
149. Bunout D, Barrera G, de la Maza P, et al. The impact of nutritional supplementation and resistance training on the health functioning of

free-living Chilean elders: results of 18 months of follow-up. *J Nutr.* 2001;131:2441S–2446S.
150. Campbell AJ, Robertson MC, Gardner MM, Norton RN, Tilyard MW, Buchner DM. Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. *Br Med J.* 1997;315:1065–1069.
151. Cress ME, Buchner DM, Questad KA, Esselman PC, de Lateur BJ, Schwartz RS. Exercise: effects on physical functional performance in independent older adults. *J Gerontol Med Sci.* 1999;54A:M242–M248.
152. Crilly RG, Willems DA, Trenholm KJ, Hayes KC, Delaquerriere-Richardson LF. Effect of exercise on postural sway in the elderly. *Gerontology.* 1989;35:137–143.
153. De Vito G, Bernardi M, Forte R, Pulejo C, Figura F. Effects of a low-intensity programme on VO2 max and maximal instantaneous peak power in elderly women. *Eur J Appl Physiol.* 1999;80:227–232.
154. Fernandez Ramirez AI, Fernandez Ramirez AS. Effect of an exercise program on physical fitness of institutionalized elderly men. *Archiv Med Deporte.* 1999;16:325–332.
155. Judge JO, Lindsey C, Underwood M, Winsemius D. Balance improvements in older women: effects of exercise training. *Phys Ther.* 1993;73:254–265.
156. Judge JO, Underwood M, Gennosa T. Exercise to improve gait velocity in older persons. *Arch Phys Med Rehabil.* 1993;74:400–406.
157. King A, Haskell W, Taylor B. Group vs home-based exercise training in healthy older men and women: a community-based clinical trial. *JAMA.* 1991;266:1535–1542.
158. King AC, Pruitt LA, Phillips W, Oka R, Rodenburg A, Haskell WL. Comparative effects of two physical activity programs on measured and perceived physical functioning and other health-related quality of life outcomes in older adults. *J Gerontol Med Sci.* 2000;55A:M74–M83.
159. Lazowski DA, Ecclestone NA, Myers AM, et al. A randomized outcome evaluation of group exercise programs in long-term care institutions. *J Gerontol Med Sci.* 1999;54A:M621–M628.
160. Lichtenstein MJ, Shields SL, Shiavi RG, Burger MC. Exercise and balance in aged women: a pilot controlled clinical trial. *Arch Phys Med Rehabil.* 1989;70:138–143.
161. Liemohn WP. Strength and aging: an exploratory study. *Int J Aging Hum Devel.* 1975;6:347–357.
162. Lord SR, Castell S. Physical activity program for older persons: Effect on balance, strength, neuromuscular control, and reaction time. *Arch Phys Med Rehabil.* 1994;75:648–652.
163. Lord S, Castell S. Effect of exercise on balance, strength and reaction time in older people. *Aust J Physiother.* 1994;40:83–88.
164. Lord SR, Lloyd DG, Li SK. Sensori-motor function, gait patterns and falls in community-dwelling women. *Age Ageing.* 1996;25:292–299.
165. Lord SR, Lloyd DG, Niruni M, Raymond J, Williams P, Stewart RA. The effect of exercise on gait patterns in older women: a randomized controlled trial. *J Gerontol Med Sci.* 1996;51A:M64–M70.
166. 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.
167. MacRae PG, Feltner ME, Reinsch S. A 1-year exercise program for older women: effects on falls, injuries, and physical performance. *J Aging Phys Activ.* 1994;2:127–142.
168. Messier SP, Loeser RF, Mitchell MN, et al. Exercise and weight loss in obese older adults with knee osteoarthritis: a preliminary study. *J Am Geriatr Soc.* 2000;48:1062–1072.
169. McAuley E, Blissmer B, Katula J, Duncan TE, Mihalko SL. Physical activity, self-esteem, and self-efficacy relationships in older adults: a randomized controlled trial. *Ann Behav Med.* 2000;22:131–139.
170. Meuleman JR, Brechue WF, Kubilis PS, Lowenthal DT. Exercise training in the debilitated aged: strength and functional outcomes. *Arch Phys Med Rehabil.* 2000;81:312–318.
171. Morey MC, Cowper PA, Feussner JR, et al. Evaluation of a supervised exercise program in a geriatric population. *J Am Geriatr Soc.* 1989;37:348–354.
172. Morey MC, Cowper PA, Feussner JR, DiPasquale RC, Crowley GM, Sullivan RJ, Jr. Two-year trends in physical performance following supervised exercise among community-dwelling older veterans. *J Am Geriatr Soc.* 1991;39:549–554.
173. Mulrow CD, Gerety MB, Kanten D, et al. A randomized trial of physical rehabilitation for very frail nursing home residents. *JAMA.* 1994;271:519–524.
174. Nelson M, Layne J, Nuernberger A. Home-based exercise training in the frail elderly: effects on physical performance. *Med Sci Sports Exerc.* 1997;29:S110.
175. Nowalk MP, Prendergast JM, Bayles CM, D'Amico FJ, Colvin GC. A randomized trial of exercise programs among older individuals living in two long-term care facilities: the FallsFREE program. *J Am Geriatr Soc.* 2001;49:859–865.
176. Oka RK, De Marco T, Haskell WL, et al. Impact of a home-based walking and resistance training program on quality of life in patients with heart failure. *Am J Cardiol.* 2000;85:365–369.
177. Okumiya K, Matsubayashi K, Wada T, Kimura S, Doi Y, Ozawa T. Effects of exercise on neurobehavioral function in community-dwelling older people more than 75 years of age. *J Am Geriatr Soc.* 1996;44:569–572.
178. Oster P, Hauer K, Specht N, Rost B, Baertsch P, Schlierf G. Muscle strength and coordination training for prevention of falls in elderly patients (translated). *Zeitschrift fur Gerontologie und Geriatrie.* 1997; 30:289–292.
179. Rikli RE, Edwards DJ. Effects of a three-year exercise program on motor function and cognitive processing speed in older women. *Res Q Exerc Sport.* 1991;62:61–67.
180. Rubenstein LZ, Josephson KR, Trueblood PR, et al. Effects of a group exercise program on strength, mobility and falls among fall-prone elderly men. *J Gerontol Med Sci.* 2000;55A:M317–M321.
181. Sauvage LRJ, Myklebust BM, Crow-Pan J, et al. A clinical trial of strengthening and aerobic exercise to improve gait and balance in elderly male nursing home residents. *Am J Phys Med Rehabil.* 1992; 71:333–342.
182. 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.
183. Thompson RF, Crist DM, Marsh M, Rosenthal M. Effects of physical exercise for elderly patients with physical impairments. *J Am Geriatr Soc.* 1988;36:130–135.
184. 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.
185. Tsuji I, Tamagawa A, Nagatomi R, et al. Randomised controlled trial of exercise training for older people: study design and primary outcome. *J Epidemiol.* 2000;10:55–64.
186. van den Ende CH, Breedveld FC, le Cessie S, Dijkmans BA, de Mug AW, Hazes JM. Effect of intensive exercise on patients with active rheumatoid arthritis: a randomised clinical trial. *Ann Rheum Dis.* 2000; 59:615–621.
187. Williams P, Lord SR. Effects if group exercise on cognitive functioning and mood in older women. *Aust NZ J Publ Health.* 1997;21: 45–52.
188. Verfaillie DF, Nichols JF, Turkel E, Hovell MF. Effects of resistance, balance and gait training on reduction of risk factors leading to falls in elders. *J Aging Phys Activ.* 1997;5:213–228.
189. McMurdo ME, Rennie L. A controlled trial of exercise by residents of old people's homes. *Age Ageing.* 1993;22:11–15.
190. McMurdo MET, Rennie LM. Improvements in quadriceps strength with regular seated exercise in the institutionalised elderly. *Arch Phys Med Rehabil.* 1994;75:600–603.
191. O'Reilly S, Muir K, Doherty M. Effectiveness of home exercise on pain an disability from osteoarthritis of the knee: a randomised controlled trial. *Ann Rheum Dis.* 1999;58:15–19.
192. Perhonen M, Komi PV, Hakkinen K, Von Bonsdorff H, Partio E. Strength training and neuromuscular function in elderly people with total knee endoprosthesis. *Scand J Med Sci Sports.* 1992;2:234–243.
193. Perkins L, Kaiser H. Results of short-term isotonic and isometric exercise programs in persons over sixty. *Phys Ther Review.* 1961;41: 633–635.
194. Petrella RJ, Bartha C. Home based exercise therapy for older patients with knee osteoarthritis: a randomized clinical trial. *J Rheumatol.* 2000;27:2215–2221.
195. Sagiv M, Fisher N, Yaniv A, Rudoy J. Effect of running versus isometric training programs on healthy elderly at rest. *Gerontology.* 1989;35:72–77.

196. Sherrington C, Lord SR. Home exercise to improve strength and walking velocity after hip fracture: a randomized controlled trial. *Arch Phys Med Rehabil*. 1997;78:208–212.
197. Rooks DS, Kiel DP, Parsons C, Hayes WC. Self-paced resistance training and walking exercise in community-dwelling older adults: effects on neuromotor performance. *J Gerontol Med Sci*. 1997;52A: M161–M168.
198. Pyka G, Lindenberger E, Charette S, Marcus R. Muscle strength and fiber adaptations to a year-long resistance training program in elderly men and women. *J Gerontol*. 1994;49:M22–M27.
199. Sforzo GA, McManis BG, Black MS, Luniewski D, Scriber KC. Resilience to exercise detraining in healthy older adults. *J Am Geriatr Soc*. 1995;43:209–215.
200. Balagopal P, Schimke JC, Ades P, Adey D, Nair KS. Age effect on transcript levels and synthesis rate of muscle MHC and response to resistance exercise. *Am J Physiol Endocrinol Metab*. 2001;280:E203–E208.
201. Bermon S, Philip P, Ferrari P, Candito M, Dolisi C. Effects of a short-term strength training programme on lymphocyte subsets at rest in elderly humans. *Eur J Appl Physiol*. 1999;79:336–340.
202. Collier C. Isotonic resistance training related to functional fitness, physical self-efficacy and depression in adults ages 65-85 [EdD Thesis]. Oklahoma State University; 1997.
203. Haykowsky M, Humen D, Teo K, et al. Effects of 16 weeks of resistance training on left ventricular morphology and systolic function in healthy men >60 years of age. *Am J Cardiol*. 2000;85: 1002–1006.
204. Hennessey JV, Chromiak JA, DellaVentura S, et al. Growth hormone administration and exercise effects on muscle fiber type and diameter in moderately frail older people. *J Am Geriatr Soc*. 2001;49:852–858.
205. Hortobagyi T, Tunnel D, Moody J, Beam S, DeVita P. Low- or high-intensity strength training partially restores impaired quadriceps force accuracy and steadiness in aged adults. *J Gerontol Biol Sci*. 2001;56A: B38–B47.
206. Jubrias SA, Esselman PC, Price LB, Cress ME, Conkley KE. Large energetic adaptations of elderly muscle to resistance and endurance training. *J Appl Physiol*. 2001;90:1663–1670.
207. Kerr D, Ackland T, Maslen B, Morton A, Prince R. Resistance training over two years increases bone mass in calcium-replete post-menopausal women. *J Bone Miner Res*. 2001;16:175–181.
208. Perrig-Chiello P, Perrig WJ, Ehrsam R, Staehelin HB, Krings F. The effects of resistance training on well-being and memory in elderly volunteers. *Age Ageing*. 1998;27:469–475.
209. Rall LC, Roubenoff R, Cannon JG, Abad LW, Dinarello CA, Meydani SN. Effects of progressive resistance training on immune response in aging and chronic inflammation. *Med Sci Sports Ex*. 1996;28:1356–1365.
210. Sartorio A, Lafortuna C, Capodaglio P, Vangeli V, Narici MV, Faglia G. Effects of a 16-week progressive high-intensity strength training (HIST) on indexes of bone turnover in men over 65 years: a randomized controlled study. *J Endocrinol Invest*. 2001;24:882–886.
211. 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.
212. Tyni-Lenne R, Dencker K, Gordon A, Jansson E, Sylven C. Comprehensive local muscle training increases aerobic working capacity and quality of life and decreases neurohormonal activation in patients with chronic heart failure. *Eur J Heart Failure*. 2001;3: 47–52.
213. Wood RH, Reyes R, Welsch MA, et al. Concurrent cardiovascular and resistance training in healthy older adults. *Med Sci Sports Exerc*. 2001; 33:1751–1758.

Received September 30, 2002
Accepted February 13, 2003