CLINICAL INVESTIGATIONS

Effective Exercise for the Prevention of Falls: A Systematic Review and Meta-Analysis

Catherine Sherrington, PhD,†‡ Julie C. Whitney, MSc,§ Stephen R. Lord, DSc,† Robert D. Herbert, PhD,* Robert G. Cumming, PhD,‡ and Jacqueline C. T. Close, MD†||*

OBJECTIVES: To determine the effects of exercise on falls prevention in older people and establish whether particular trial characteristics or components of exercise programs are associated with larger reductions in falls.

DESIGN: Systematic review with meta-analysis. Randomized controlled trials that compared fall rates in older people who undertook exercise programs with fall rates in those who did not exercise were included.

SETTING: Older people.

PARTICIPANTS: General community and residential care.

MEASUREMENTS: Fall rates.

RESULTS: The pooled estimate of the effect of exercise was that it reduced the rate of falling by 17% (44 trials with 9,603 participants, rate ratio (RR) = 0.83, 95% confidence interval (CI) = 0.75–0.91, $P<.001$, $I^2 = 62\%$). The greatest relative effects of exercise on fall rates (RR = 0.58, 95% CI = 0.48–0.69, 68% of between-study variability explained) were seen in programs that included a combination of a higher total dose of exercise (>50 hours over the trial period) and challenging balance exercises (exercises conducted while standing in which people aimed to stand with their feet closer together or on one leg, minimize use of their hands to assist, and practice controlled movements of the center of mass) and did not include a walking program.

CONCLUSION: Exercise can prevent falls in older people. Greater relative effects are seen in programs that include exercises that challenge balance, use a higher dose of exercise, and do not include a walking program. Service providers can use these findings to design and implement exercise programs for falls prevention. **J Am Geriatr Soc 2008.**

Key words: falls; exercise; meta-analysis

From the *Musculoskeletal Division, The George Institute for International Health and ‡School of Public Health, University of Sydney, Sydney, Australia; †Falls and Balance Research Group, Prince of Wales Medical Research Institute, University of New South Wales, Sydney, Australia; §Clinical Age Research Unit, Kings College Hospital, London, United Kingdom; and ||Department of Geriatric Medicine, Prince of Wales Hospital, Sydney, Australia.

Address correspondence to Dr. Catherine Sherrington, The George Institute for International Health, PO Box M201, Missenden Road, Sydney NSW 2050, Australia. E-mail: csherrington@george.org.au

DOI: 10.1111/j.1532-5415.2008.02014.x

The development and implementation of effective and cost-efficient strategies to prevent falls in older people is an urgent global health challenge. In developed countries, life expectancy for people aged 65 years old is approximately 17 years for men and 21 years for women. At least one-third of people aged 65 and older fall at least once annually,[1] and falls account for more than half of the injury-related hospitalizations for older people.[2] Fall rates in the general older population are reported to be 1.2 falls per person year.[3]

Falls in older people are not purely random events but can be predicted by assessing a number of risk factors.[4,5] Some of these risk factors (e.g., reduced muscle strength and impaired balance and gait) can be modified using exercise, whereas others (e.g., poor vision, psychoactive medication use) require different intervention approaches. Exercise can be used as a stand-alone falls prevention intervention or as a component of a multifaceted program. Multifaceted interventions can prevent falls in the general community, in those at greater risk of falls, and in residential care facilities.[4,6]

Many trials have sought to establish the specific effect of exercise on fall rates, but a large proportion of these trials have been underpowered. The best way to interpret these trials may be to pool their data in a meta-analysis, but trials of the effects of exercise on fall rates vary in their quality, have been conducted on a range of populations, and employ exercise programs that differ greatly in their aims and content. Meta-analysis should therefore involve exploration of whether these factors "explain" (are associated with) estimates of the effect of exercise programs.[7,8]

A Cochrane review of fall prevention strategies[6] conducted separate meta-analyses on different forms of exercise and concluded that some exercise programs can prevent falls in community dwellers (e.g., home exercise program of balance and strength training, a Tai Chi group program) but

0002-8614/08/$15.00

that others are unlikely to be beneficial (brisk walking in women with an upper limb fracture in the previous 2 years) or require further investigation (untargeted group-based exercise interventions and individual lower-limb strength training). A limitation to this approach is that it combines programs that may be different (e.g., group programs that are of low and high intensity) and separates programs that share key features (e.g., balance training).

This study sought to establish the effect of exercise on fall rates, with a major aim of explaining between-trial variability. Meta-regression methods were used to investigate whether particular features of study populations, exercise programs, and study design were associated with the size of estimates of effects of exercise on fall rates.

METHODS

Data Sources and Searches

A literature search was conducted in May 2007. OVID was used to search MEDLINE, EMBASE, and CINAHL. Search filters developed by the Scottish Intercollegiate Guidelines Network (SIGN; http://www.sign.ac.uk/methodology/filters.html) to identify randomized trials were combined with a strategy to identify studies of the effects of exercise (available from the authors on request) and search terms from the relevant Cochrane review[6] (to identify studies of falls prevention). The search was supplemented with searches of PubMed, the Physiotherapy Evidence Database (http://www.pedro.fhs.usyd.edu.au), SafetyLit (http://www.safetylit.org/archive.htm), and Prevention of Falls Network Europe (ProFaNE; http://www.profane.eu.org/). The reference list of the Cochrane review[6] and other reviews and the updated search results provided by the trial search coordinator of the Cochrane Bone, Joint and Muscle Trauma Group were also checked.

Study Selection

Published randomized trials conducted in older people in which the primary intervention being evaluated was exercise and the outcome was number of falls, number of fallers, or rate of falls were reviewed. Trials were ineligible if non-exercise interventions were a major ($>25\%$ of time) component of the intervention being evaluated.

To determine eligibility of identified trial reports, two investigators (CS, RDH) independently scanned titles and abstracts. If it was clear that the control group received exercise or the intervention program involved substantial ($>25\%$ of time) additional nonexercise interventions, the study was excluded. The full articles were obtained for the remaining titles. Differences of opinion of the two investigators about study eligibility were resolved by discussion.

Data Extraction and Quality Assessment

Two of the authors (CS and SRL or JCTC) extracted data on study characteristics and estimates of effect of exercise from each study. Differences were resolved by discussion with a third investigator (SRL or JCTC).

The quality of study design was assessed by noting whether allocation to groups was concealed and analysis was according to intention to treat.[9]

The studies were described in terms of population (dwelling situation and risk status), presence and intensity of different exercise program components (addressing strength, balance, endurance, flexibility, and walking), broad aspects of the exercise program (amount of supervision, progression of exercises, modifying in type or intensity of exercise, adherence to program and overall dose of exercise), and study design (concealed allocation to groups and intention-to-treat analysis). Criteria for coding are summarized in Table 1. The majority of characteristics were coded on 3- to 5-point scales, but all were dichotomized a priori for the analysis. For several variables, analyses were conducted using two different cutpoints for dichotomization. The cutpoint that explained the most variability was used and is reported in the tables.

Five of the trials had two exercise groups and one control group. For these trials, estimates of the effects of each exercise intervention were obtained. To avoid "double counting" of control subjects from these trials, the total falls and subject numbers in the control group were allocated in proportion to the participant numbers in each intervention group. There were thus 49 comparisons in the meta-analysis.

Estimates of the effect of exercise were extracted from each trial. Where possible, estimates of incidence rate ratios (IRRs) from negative binomial regression models (6 studies), person-time analyses (1 study), or hazard ratios from proportional hazards models that allowed for multiple falls per person (6 trials) were used. Alternatively, data on the total number of falls ($n = 20$) or number of falls per person ($n = 6$) and exposure times (person-years of follow-up using actual follow-up times and number of participants providing data where reported) were used to calculate IRRs. Three trials reported only the incidence proportions of fallers in intervention and control groups, and two trials reported only the hazard ratios for time to first fall. For these trials, the ratio of incidence proportions or the hazard ratio was used as an estimate of the IRR. Where possible, unadjusted falls rates and longer follow-up times were used (e.g., in an article such as[10], which presented 6- and 12-month falls data, the 12-month data were used).

Four of the trials were cluster-randomized. Two of these accounted for the effect of clustering. For the other two, the variance of estimates for clustering was adjusted by assuming an intracluster correlation of 0.01.[11,12]

Data Synthesis and Analysis

A random-effects meta-analysis was conducted. Comprehensive Meta-Analysis software (Version 2, Biostat, Englewood NJ) was used to calculate a pooled IRR. Statistical heterogeneity was quantified with the I[13] and Q statistics. Publication bias was assessed using Egger's test. The pooled effect was also calculated in STATA (Stata Corp., College Station, TX) using the "metan" command.[14] Influence was assessed in STATA using the "metaninf" command.[14]

Sensitivity analyses were conducted to assess the effect of excluding the trials for which only risk ratios or hazard ratios were available and excluding the cluster randomized trials.

Table 1. Summary of Included Trials (n = 44) and Comparisons (n = 49) Showing Control Group Fall Rate over Follow-Up Period, Sample Size, Length of Follow-Up, Estimate of Effect of Intervention, and Number and Percentage of Trials with Each Population, Program, or Study Quality Descriptor

First Author, Year, and Program Type If Two Intervention Groups	Control Group Falls/ Person-Year or % Who Fell During Follow-Up Period	Data Extracted	Sample Size at Randomization	Follow-Up (Months)	Estimate of Fall Rate Ratio (95% CI)	High-Support Residential Care[a]	Population at Greater Risk[b]	Average Age 75 and Older	Moderate-to High-Intensity Strength Training[c]	High-Challenge Balance Training[d]	Moderate-to High-Intensity Endurance Training[e]	Stretching Program[f]	Walking Program[g]	Moderatly to Highly Supervised Exercise[h]	Exercises Progressed Weekly or More[i]	Exercises Modified in Type or Intensity[j]	Good Adherence[k]	50+Total Hours of Exercise[l]	Concealed Allocation to Groups[m]	Intention to Treat Analysis[n]
Barnett, 2003[30]	0.97	IRR	163	12	0.60 (0.36–0.99)	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y
Bunout, 2005[31]	0.18	F/PY	298	12	1.22 (0.70–2.14)	N	N	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y	N	N
Buchner, 1997[32]	0.81	Rate Ratio	105	25	0.61 (0.39–0.93)	N	Y	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	N	Y
Campbell, 1997[33]	1.34	HR-4	233	12	0.68 (0.52–0.90)	N	Y	Y	Y	Y	Y	N	Y	N	N	Y	N	Y	Y	Y
Campbell, 1999[34]	0.97	HR-M	93	10	0.87 (0.36–2.09)	N	Y	N	Y	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y
Campbell, 2005[35]	1.13	IRR	391	12	1.15 (0.82–1.61)	N	Y	Y	Y	Y	Y	N	Y	N	N	Y	N	Y	Y	Y
Carter, 2002[36]	0.52	F/PY	93	5	0.88 (0.32–2.41)	N	N	N	N	N	N	Y	N	N	N	Y	Y	N	N	N
Cerny, 1998[37]	0.46	F/PY	28	6	0.87 (0.17–4.29)	N	N	N	Y	N	Y	Y	Y	N	N	N	N	Y	N	N
Day, 2002[38]	64%	HR-M	1090	18	0.82 (0.70–0.97)	N	N	Y	N	N	N	N	N	N	N	N	Y	N	Y	Y
Ebrahim, 1997[39]	0.55	F/PY	165	24	1.29 (0.90–1.83)	N	Y	N	N	N	Y	N	Y	N	N	Y	Y	Y	Y	N
Faber, 2006[40] "Functional walking"	2.50	FR	278	12	1.32 (1.03–1.69)	N	Y	Y	N	Y	N	N	Y	Y	N	Y	Y	N	N	N
Tai Chi					0.96 (0.76–1.22)	N	Y	Y	N	Y	N	Y	Y	Y	N	Y	Y	N	N	N
Green, 2002[41]	31%	Risk ratio	170	9	1.34 (0.87–2.07)	N	Y	N	N	N	N	N	Y	Y	N	Y	Y	N	Y	Y
Hauer, 2001[42]	60%	Risk ratio	57	6	0.75 (0.46–1.25)	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Korpelainen, 2006[43]	0.53	F/PY	160	30	0.79 (0.59–1.05)	N	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
Latham, 2003[44]	2.7	F/PY	243	6	1.08 (0.87–1.35)	N	Y	Y	Y	N	N	Y	N	N	Y	Y	Y	N	Y	Y
Li, 2005[10]	0.76	F/PY	256	12	0.45 (0.33–0.62)	N	N	Y	N	Y	N	N	N	N	N	N	Y	Y	N	Y
Lin, 2007[45]	0.88[j]	FR	150	6	0.67 (0.32–1.41)j	N	Y	Y	N	Y	N	Y	Y	N	Y	Y	N	N	N	N
Lord, 1995[46]	0.63	F/PY	197	12	0.85 (0.57–1.27)	N	N	N	N	Y	Y	Y	Y	N	N	N	Y	Y	N	N
Lord, 2003[47]	0.85	IRR (cl)	551	12	0.78 (0.62–0.99)	N	Y	Y	N	Y	Y	Y	Y	N	N	N	N	Y	N	Y
Liu-Ambrose, 2004[48] strength	0.65	F/PY	104	6	1.8 (0.67–4.85)	N	N	Y	Y	N	N	N	N	Y	Y	Y	Y	N	N	Y
Agility					1.03 (0.36–2.98)	N	N	Y	N	Y	Y	N	N	Y	N	N	Y	N	N	Y
Luukinen, 2007[49]	1.23	HR-M	486	16	0.93 (0.80–1.09)	N	Y	Y	N	N	N	N	Y	N	N	Y	N	Y	N	Y
McMurdo, 1997[50]	0.32	F/PY	118	24	0.53 (0.28–0.98)	N	N	N	N	N	N	N	N	N	N	N	Y	Y	N	N
Madureira, 2007[51]	0.90	FR	66	12	0.48 (0.25–0.93)	N	N	N	N	Y	N	Y	Y	N	N	N	Y	Y	N	N
Means, 2005[52]	1.18	FR	338	6	0.41 (0.21–0.77)	N	N	N	Y	N	Y	Y	Y	Y	Y	Y	Y	N	N	N
Morgan, 2004[53]	31%	HR	294	12	1.05 (0.66–1.68)	N	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	N	N	Y
Mulrow, 1994[54]	2.05	F/PY	194	4	1.26 (0.90–1.76)	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	N	Y	N
Nowalk, 2001[55] strength/ endurance	75%	Risk ratio	112	24	0.96 (0.63–1.46)	N	Y	Y	Y	N	Y	N	Y	N	N	Y	Y	N	N	N
Tai Chi					0.77 (0.46–1.28)	N	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N
Protas, 2005[56]	37.6	F/PY	18	0.5	0.62 (0.26–1.48)	N	Y	N	N	Y	Y	N	Y	Y	N	Y	Y	N	N	Y
Reinsch, 1992[57]	40%	HR (cl)	230	12	1.24 (0.77–1.98)	N	N	N	N	N	N	N	N	N	N	N	Y	Y	N	N
Resnick, 2002[58]	0.56	FR	20	6	0.71 (0.04–11.58)	N	Y	Y	N	N	Y	N	Y	Y	N	Y	Y	N	N	N
Robertson, 2001[59]	1.01	IRR	240	12	0.54 (0.32–0.91)	N	Y	Y	Y	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y

(Continued)

Table 1. (Contd.)

First Author, Year, and Program Type If Two Intervention Groups	Control Group Falls/ Person-Year or % Who Fell During Follow-Up Period	Data Extracted	Sample Size at Randomization	Follow-Up (Months)	Estimate of Fall Rate Ratio (95% CI)	High-Support Residential Care[a]	Population at Greater Risk[b]	Average Age 75 and Older	Moderate-to High-Intensity Strength Training[c]	High-Challenge Balance Training[d]	Moderate-to High-Intensity Endurance Training[e]	Stretching Program[f]	Walking Program[g]	Moderatly to Highly Supervised Exercise[h]	Exercises Progressed Weekly or More[i]	Exercises Modified in Type or Intensity[j]	Good Adherence[k]	50+Total Hours of Exercise[l]	Concealed Allocation to Groups[m]	Intention to Treat Analysis[n]
Rubenstein, 2000[60]	2.25	F/PY	59	3	0.90 (0.42–1.91)	N	Y	Y	Y	N	Y	N	Y	Y	N	Y	Y	Y	Y	N
Sakamoto, 2006[61]	1.14	F/PY	553	6	0.82 (0.64–1.04)	Y	Y	Y	N	N	N	N	N	Y	N	N	Y	N	N	N
Schoenfelder, 2000[62]	3.43	F/PY	16	6	3.06 (1.61–5.82)	Y	Y	Y	Y	N	N	N	Y	Y	N	N	Y	N	N	N
Schnelle, 2003[63]	0.69	F/PY	190	8	0.62 (0.38–0.98)	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	N	N
Sihvonen, 2004[64]	1.57	F/PY	27	12	0.38 (0.17–0.87)	Y	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	N	Y	N
Skelton, 2005[21]	3.21	IRR	100	20	0.69 (0.50–0.96)	N	Y	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y
Steinberg, 2000[65]	0.85	FR (cl)	252	17	0.90 (0.79–1.03)	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Suzuki, 2004[66]	0.46	F/PY	52	20	0.35 (0.14–0.90)	N	N	Y	Y	Y	N	N	N	N	N	N	Y	N	N	Y
Toulotte, 2003[67]	1.95	F/PY	20	4	0.08 (0.00–1.37)	Y	Y	Y	N	Y	N	N	Y	Y	N	N	Y	N	N	N
Voukelatos, 2007[68]	0.74[j]	IRR	702	6	0.67 (0.46–0.97)	N	N	N	N	Y	N	N	N	N	N	N	Y	N	Y	Y
Wolf, 1996[69] Tai Chi	3.18	HR-M	200	20	0.51 (0.36–0.73)	N	N	Y	N	Y	N	N	N	N	N	N	Y	Y	N	N
Balance					0.98 (0.71–1.34)	N	N	Y	N	N	N	N	N	Y	Y	Y	Y	N	N	N
Wolf, 2003[70]	60%	HR-M (cl)	311	11	0.75 (0.52–1.08)	N	Y	Y	N	Y	N	N	N	N	N	N	Y	Y	N	Y
Woo, 2007[22] Tai Chi	0.52	F/PY	180	12	0.49 (0.24–0.99)	N	N	N	N	Y	N	N	N	N	N	N	Y	Y	Y	N
Strength					0.78 (0.41–1.48)	N	N	N	Y	N	N	N	N	N	N	N	Y	Y	Y	N
Total, n (%)						6 (12)	29 (59)	32 (65)	19 (39)	25 (51)	20 (41)	12 (24)	27 (55)	23 (47)	14 (29)	28 (57)	41 (84)	25 (51)	16 (33)	22 (45)

[a] Mainly high-support care facility (nursing home) residents.

[b] The presence of a particular falls risk factor was used as inclusion criteria to the study, or the entire population was known to be at greater risk (e.g., aged care facility residents, aged $\geq$75, impaired strength or balance, previous falls).

[c] Moderate intensity (40–60% of the one repetition maximum (1RM; i.e., a weight so heavy that it can only be lifted once) or high intensity (>60% 1RM).

[d] Moderately challenging = two of the following criteria or highly challenging = all three criteria: movement of the center of mass, narrowing of the base of support, and minimizing upper limb support.

[e] Moderate intensity = 40% to 60% of maximum heart rate, some increase in breathing or heart rate, or perceived exertion of 11 to 14 on the Borg scale; high intensity = >60% of maximum heart rate or heart rate reserve, large increase in breathing or heart rate (conversation is difficult or broken), or perceived exertion of $\geq$15 on the Borg scale.

[f] Short- or long-duration stretches were specifically mentioned.

[g] Walking program or practice was specifically mentioned.

[h] 10 or fewer participants per instructor.

[i] Most exercises progressed at least weekly.

[j] Type or intensity of most exercises was designed for each individual based on an assessment.

[k] $\geq$75% participants attended 50% or more sessions or >50% attendance rate.

[l] $\geq$50 hours of exercise with instructor plus prescribed home exercise over study period.

[m,n] Coded using PEDro rating scale[71] http://www.pedro.fhs.usyd.edu.au.

[j] Additional data provided by the author.

IRR = incidence rate ratios from analysis with negative binomial models from trial reports; F/PY = Falls per person-year (by group) were used to calculate rate ratio; rate ratio = rate ratio from trial reports ; FR = fall rates (by group) were used to calculate rate ratios; HR = hazard ratio from Cox models or survival analyses considering time to first fall in trial reports; HR-M = hazard ratio from extensions to Cox models that allow for multiple events from trial reports; HR-4 = hazard ratio from extensions to Cox models that allow for up to four events from trial reports; Risk ratio = risk ratio was calculated from the proportion of fallers in each group; cl = cluster randomized trials; N = no; Y = yes.

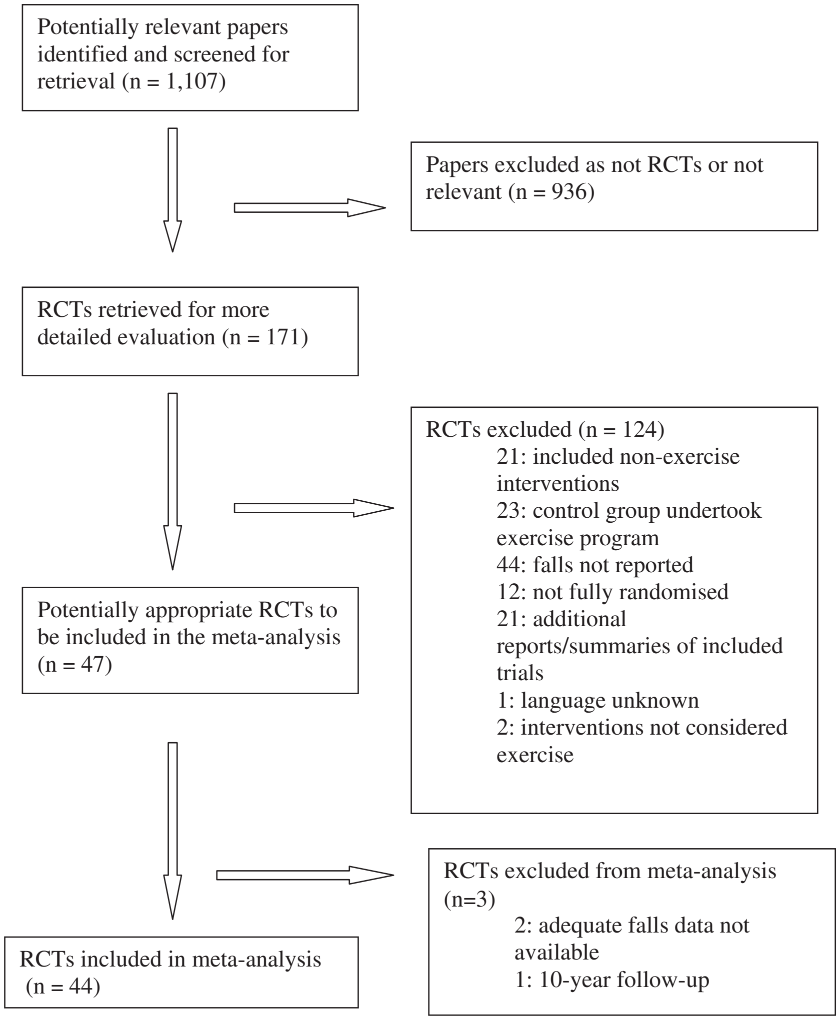

Figure 1. QUOROM statement[16] flow diagram.

Heterogeneity was investigated with random effects meta-regression using the "metareg" command in STATA.[14] Univariate meta-regressions were conducted to assess the associations between each study characteristic and estimates of the effect of exercise. The five strongest predictors were then entered into a multivariate model, and a backwards elimination approach was used to remove those that did not contribute significantly to the model.[15] The best model was identified by examining the proportion of overall between-trial variability explained by each model (as assessed using the τ^2 statistic). Subsequent models were then assessed to determine whether other combinations of the five variables that explained the most variance in the univariate analyses could account for similar variability in exercise effect. The exponentiated coefficients of the meta-regression models were the "ratio of rate ratios," which estimate of the effect of each variable or combination of variables on the effect of exercise on fall rates. The "lincom" command in STATA was used to assess the effect of specific combinations of variables from the multivariate models on the pooled effect of exercise on fall rates.

To assess the extent of correlation between variables, phi coefficients were calculated for each pair of variables in the models using SPSS (SPSS, Inc., Chicago, IL). Pairs of variables were not included in the same models if they had phi correlation coefficients greater than 0.6.

RESULTS

Trial Flow and Study Characteristics

Searching yielded 171 trials, of which 47 were potentially appropriate for inclusion in the meta-analysis (Figure 1).[16] Two trials were then excluded, because they did not report sufficient data to estimate effects of exercise on falls, and one trial was excluded because it presented only 10-year follow-up data. Five trials had two intervention groups, so the 44 included trials yielded 49 estimates of the effects of exercise. The included trials involved a total of 9,603 participants. Characteristics of the trials are summarized in Table 1. The majority of trials were conducted in older people living in the general community; six trials were conducted in residents of high care residential facilities (nursing homes). Twenty-nine trials included only participants who could be defined as being at greater risk of falls. Most of the exercise programs (n = 23) evaluated in the trials were conducted under supervision, with fewer than 10 participants per instructor. In most of the programs, the intensity or type of exercise was tailored to the individual (n = 28).

Effects of Exercise on Fall Rates

The pooled estimate of the incidence rate ratio (the effect of exercise on fall rates) was 0.83 (95% confidence interval (CI) = 0.75–0.91, $P<.001$). There was a moderate to high level of heterogeneity in estimates of the effects of exercise ($I^2 = 62\%$, Q = 125.5, degrees of freedom (df) = 48, $P<.001$; Figure 2). No study exerted excessive influence, because omission of any single study had little effect on the pooled estimate (the 95% CIs remained between 0.74 and 0.92). There was no conclusive evidence of small sample bias (Egger's Test of the Intercept $B0 = -0.675$, 95% CI = -4.10–0.06, $t = 1.544$, $df = 47$, $P = .13$, and the funnel plot of standard error and log rate ratio was quite symmetrical). Sensitivity analysis revealed similar effects when the meta-analysis was conducted without the five trials for which only proportion of fallers or time to first fall were available (pooled RR = 0.80, 95% CI = 0.73–0.89, 43 comparisons) and when the four cluster randomized trials were omitted (pooled RR = 0.82, 95% CI = 0.73–0.91, 44 comparisons).

Trial-Level Determinants of Effects of Exercise

The proportion of between-study variability in effect sizes (effects of exercise on fall rates) explained by each of the study and program characteristics is shown in Table 2. The total dose of exercise (22%, dichotomized as ≤50 hours over the trial period) and the presence of highly challenging balance training in exercise programs (19%) explained the most variability. The presence of either of these features in the exercise programs tested in the included trials was associated with a greater reduction in fall rates (ratio of rate ratios = 0.80, 95% CI = 0.65–0.99, $P = .04$ for dose; ratio of rate ratios = 0.76, 95% CI = 0.62–0.93, $P = .009$ for balance training).

There was an indication of a lesser effect of exercise on fall rates in the trials that were conducted in higher-risk populations; this variable explained 12% of between-study variability ($P = .09$). To explore this finding, a post hoc analysis was undertaken using the control rate of falls during the follow-up period dichotomized at 1 (close to the median) and 2 falls per person-year. In the 41 comparisons for which these data were available, there was a lesser effect of exercise on falls in the trials in which the control groups had an average fall rate of 2 or more per person-year (ratio of rate ratios = 1.36, 95% CI = 1.05–1.77, $P = .02$, 17% between-study variability explained).

A meta-regression model with three variables explained 68% of the between-study variability of the effect

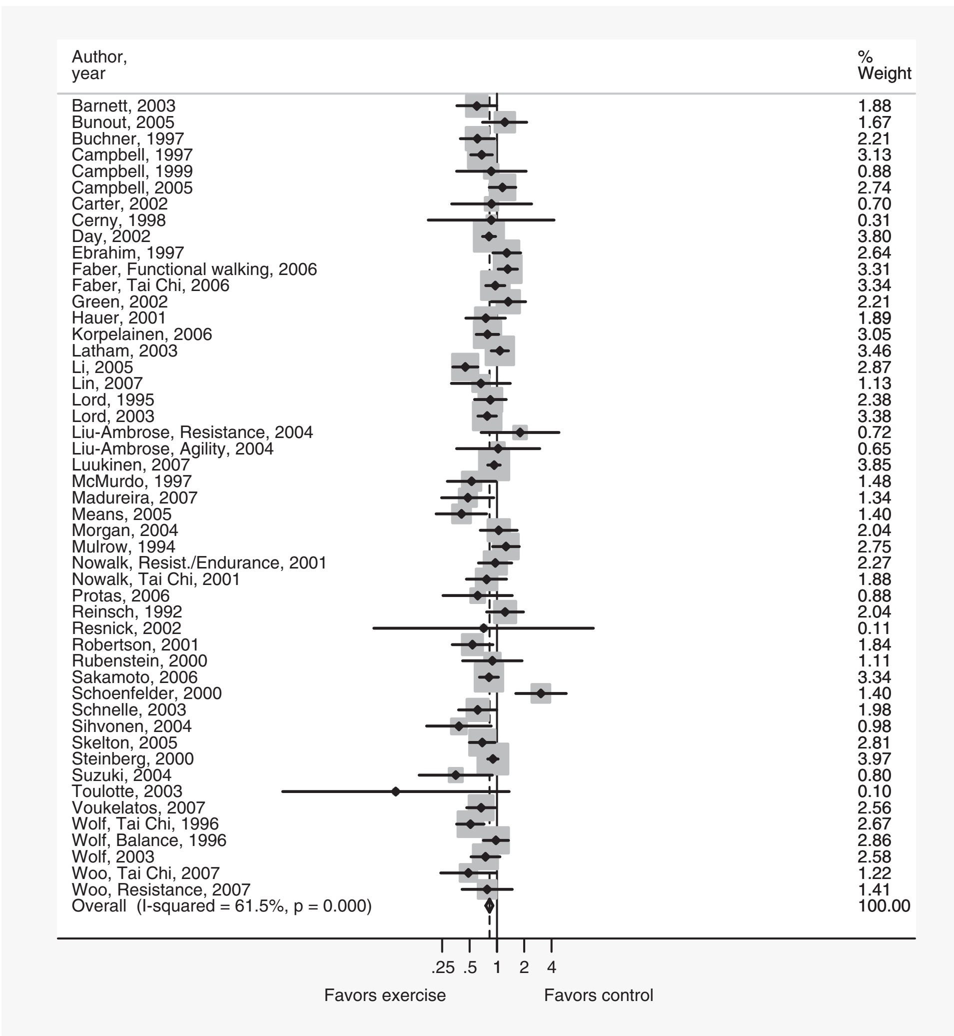

Figure 2. Forest plot from the meta-analysis of exercise on fall rates showing estimates of effect of exercise on falls with 95% confidence intervals and relative weight for each trial.

Table 2. Trial-Level Determinants of Effects of Exercise: Univariate and Multivariate Associations

Characteristic	Comparisons with This Feature, n	Ratio of Rate Ratios (95% Confidence Interval)*	*P*-Value	Variance Explained, %†
Study population				
Mainly care facility residents	13	1.17 (0.92–1.49)	.19	4
Mainly high-support care facility residents	6	1.16 (0.81–1.65)	.41	0
Study population at high risk	29	1.21 (0.97–1.50)	.09	12
Average age ≥75	32	1.05 (0.83–1.33)	.66	0
Control group fall rate > 2 per person per year during follow-up period (p1)	10	1.36 (1.05–1.77)	.02	17
Type and intensity of exercise				
Moderate- or high-intensity strength training	19	1.09 (0.87–1.36)	.47	0
High-intensity strength training	5	1.16 (0.81–1.67)	.40	0
Moderate- or high-challenge balance training	34	0.75 (0.60–0.94)	.01	14
High-challenge balance training	25	0.76(0.62–0.93)	.009	19
Moderate- or high-intensity endurance training	20	0.94 (0.75–1.18)	.58	0
Stretching program	12	0.89 (0.69–1.15)	.37	0
Walking program (any)	27	1.19 (0.96–1.46)	.11	9
Longer walking program (≥20 minutes)	8	1.07 (0.79–1.45)	.67	0
Exercise program features				
Supervised exercise	41	0.89 (0.68–1.17)	.40	0
Moderately to highly supervised exercise (10 or fewer participants per instructor)	23	1.16 (0.93–1.44)	.18	3
Progressive (monthly or more)	32	1.12 (0.89–1.40)	.34	0
More progressive (weekly or more)	14	1.01 (0.79–1.28)	.96	0
Intensity or type modified (most exercises)	28	1.21 (0.98–1.49)	.08	15
Good adherence	41	0.97 (0.73–1.27)	.80	0
Dose with instructor ≥30 hours	25	0.95 (0.77–1.19)	.67	0
Dose of prescribed home program ≥30 hours	12	0.84 (0.66–1.07)	.15	2
Total (instructor and home program) dose ≥50 hours over trial	25	0.80 (0.65–0.99)	.04	22
Total dose ≥8 hours per month (p2)	19	1.04 (0.83–1.30)	.72	0
Total length of exercise program ≥12 months (p2)	20	0.98 (0.78–1.22)	.83	0
Study design features				
Concealed allocation to groups	16	1.05 (0.83–1.32)	.69	0
Intention to treat analysis	22	0.91 (0.73–1.12)	.36	3
Multivariate (adjusted)				68
High-challenge balance training	25	0.79 (0.66–0.95)	.01	
Total dose ≥50 hours	25	0.80 (0.67–0.96)	.02	
Walking program (any)	27	1.32 (1.11–1.58)	.003	

* The "ratio of rate ratios" is the estimate of the effect of each variable or combination of variables on the effect of exercise on fall rates.

† The proportion of between-trial variability (as assessed using the τ^2 statistic) of the model with no covariates that is explained by model with these variable(s) included.

(p1) post hoc analyses undertaken to explore importance of not being at high risk. This analysis includes only the 41 trials for which control fall rate data were available. The percentage variance explained was calculated from the variance in a meta-analysis with these 41 trials only.

(p2) post hoc analyses undertaken to explore importance of total dose.

of exercise on fall rates. In this model, each of the predictor variables (exercise program descriptors) was independently and significantly ($P < .05$) associated with the effect of exercise on falls (Table 2). The regression model was used to obtain adjusted estimates of the effects of exercise on fall rates in studies with and without each of the three predictive characteristics (Table 3). The greatest effects of exercise on falls (RR = 0.58, 95% CI = 0.48–0.69) were obtained from programs that challenged balance to a high extent, included a higher total dose of exercise, and did not include a walking program.

A sensitivity analysis found that excluding the six comparisons from studies undertaken in nursing homes had little effect on the results. The same three variables were retained in the model, and the model explained 65% of intertrial variability.

Models were also developed in which the other two variables that explained more than 10% of between-study variability in univariate analyses (a high-risk population and a tailored exercise program) replaced the variable regarding the inclusion of walking in an exercise program, but these models explained less than 50% of between-study variability.

Table 3. Adjusted Effects of Exercise on Falls

Program	High Balance Challenge	Mod-Low Balance Challenge
	Adjusted Pooled Rate Ratios (95% Confidence Interval)	
High dose and walking	0.76 (0.66–0.88)	0.96 (0.80–1.16)
High dose, no walking	0.58 (0.48–0.69)	0.73 (0.60–0.88)
Low dose and walking	0.95 (0.78–1.16)	1.20 (1.00–1.44)
Low dose, no walking	0.72 (0.60–0.87)	0.91 (0.79–1.05)

The adjusted pooled rate ratios estimate the effects of exercise on fall rates in trials with different combinations of exercise program components.

DISCUSSION

This systematic review provides strong evidence that exercise programs can reduce fall rates in older people. The overall reduction of 17% based on 44 trials involving 9,603 participants provides confidence that these findings are robust and generalizable to a broad section of older people. Furthermore, the meta-regression analysis model revealed that three factors (balance training, exercise dose, and the absence of a walking program) are associated with the efficacy of exercise programs.

The inclusion of balance training in exercise programs appears to be important. This finding is consistent with the Frailty and Injuries: Cooperative Studies of Intervention Techniques prospective meta-analysis of individual participant data from eight trials, which found a pooled estimate of a 17% lower falls risk from exercise programs that included balance training but not from other forms of exercise.[17]

Inclusion of balance training may help to explain why several intervention strategies that appear to be different are similarly effective in substantially reducing fall rates. For example, effective programs, such as Tai Chi[10] conducted in a group setting and the home-based Otago Exercise Programme,[18] primarily include balance training. These trials also show that, with appropriate prescription and supervision, exercise that challenges balance can be administered safely. For example, it has been demonstrated that the Otago Exercise Programme is feasible and safe for older people to undertake at home and produced a 35% reduction in falls and falls-related injury.[18]

Total exercise dose also explained a significant and independent amount of variability with regard to the effectiveness of the exercise trials. This finding is consistent with trials of stroke rehabilitation, which have found better outcomes with more-intense exercise.[19] The measure of exercise dose combined frequency of exercise on a weekly basis with program length, and this measure proved to be superior in discriminating between less-effective and more-effective trials than weekly exercise frequency or program length when analyzed separately. Although programs varied markedly with regard to these factors, the criterion for a minimal effective exercise dose would equate to a twice-weekly program running over 25 weeks. This finding has important implications for service delivery, because many programs are offered for shorter periods than this, typically for 10 weeks. Strategies for achieving long-term exercise participation could include combining supervised group exercise with interspersed or follow-on home exercise programs.

Exercise programs that did not include walking reduced fall rates more than exercise programs that involved walking. One explanation might be that participants are exposed to greater risk of falls while walking, although the published trials do not indicate that many falls occurred when participants were undertaking the prescribed walking programs. An alternative explanation is that time spent walking takes the place of time spent undertaking balance training (the most effective exercise) in time-limited programs. Falls are not the only important outcome for exercise trials in older people, and other studies have shown that walking programs have health benefits including improved fitness, weight loss, and lower blood pressure.[20] For these reasons, walking programs could be included in exercise programs for older people, but if fall prevention is the primary aim, walking programs should be included only if they are in addition to a balance training program of adequate intensity and duration. Ideally, there should also be some assessment of whether a walking program will unduly increase the risk of falls for individual participants. Further research into the relationship between walking programs and falls is required.

There is an indication that lesser relative reductions in fall rates were seen in studies of exercise that included people at a high risk of falls. This provides support for a population-based approach to falls prevention with appropriate exercise. However the absolute effects of exercise may be greater in high-risk populations, such as nursing home residents or those with previous falls. For example, one trial[21] found a 31% difference between fall rates in the intervention and control groups in a sample of multiple fallers in which the control group fall rate was 3.2 falls per person-year. This equates to the prevention of 1 fall per person-year. A trial in a lower-risk population in which the control group rate was 0.52 falls per person-year[22] found a 51% between-group difference, which represented the prevention of 0.27 falls per person-year. It could also be argued that the consequences of falls (e.g., fracture rates, hospital admissions, and moves to institutional care) may also be more significant in higher-risk populations. For these reasons, exercise for falls prevention should be undertaken in populations at high risk and in the general older community.

The studies that were conducted in high-risk populations were more likely to include walking programs (phi = 0.42, $P = .003$) and modified exercise (phi = 0.46, $P < .001$). No two of these three variables simultaneously made an independent contribution to the models. Thus it is possible that risk status confounds the effect of walking and modifying of exercise on falls.[9]

Although poorer muscle strength is a risk factor for falls,[23] the presence of moderate- or high-intensity strength training was not found to be associated with a greater effect of exercise on falls. This finding is more definitive than previous meta-analysis findings. One previous study[7] found some indication of an effect of strength training on the proportion of fallers (pooled adjusted risk ratio from 9 studies was 0.82, 95% CI = 0.48–1.41) but not on the rate of falls (pooled adjusted incidence RR from 14 studies was 1.04, 95% CI = 0.76–1.42), and another[17] found the pooled effect of resistance training on falls to be 0.96 ($P = .59$). It is likely that impaired balance is a stronger risk factor for falls than poor muscle strength and that this finding is in keeping with previous findings that strength training increases strength but has less-clear effects on balance abilities.[24,25] Nevertheless, the relationship between strength and falls may be nonlinear. This may mirror the nonlinear relationship between strength and gait speed[26] (i.e., once a person has sufficient strength to avoid falling, further strength training may not be of additional benefit). Like walking programs, strength training is likely to provide many older people with other health benefits,[25,27] but it does not seem to be the optimal intervention for falls prevention.

This systematic review had certain limitations. First, because a meta-regression of trial-level characteristics was used, some caution is warranted when interpreting the findings.[28] The analysis permits inference only about the effects of trial-level characteristics (e.g., whether the trial included high-risk participants or average exercise dose) on trial-level estimates of effects of exercise. Inferences cannot be made about the effects of the characteristics of individuals (e.g., presence of risk factors in individual participants) or of participant-specific features of the intervention (e.g., the dose of exercise given to an individual) on the effects of exercise on falls risk in individual participants.[29] Despite multivariate adjustment, there is the possibility that the conclusions are subject to confounding by unmeasured variables or by failure to adjust completely for measured variables. There is also a possibility that the coding of program content does not reflect the real nature of the program, because the coding was based on the short descriptions of often-complex programs in the published articles. Nonetheless, the findings are consistent with the little that is known about optimal exercise protocols from analyses at the level of individual participants.[17]

In conclusion, this analysis confirms that exercise can reduce fall rates in older people and identifies the important components of effective exercise intervention strategies. It confirms the importance of balance training in falls prevention and the need for exercise to be sustained over time. Service providers can use these findings to design and implement exercise programs for preventing falls.

ACKNOWLEDGMENTS

This review was undertaken as part of the work of ProFaNE, of which J. C. T. Close is a principal contractor and J. C. Whitney, C. Sherrington, S. R. Lord, and R. G. Cumming are network associates. C. Sherrington, S. R. Lord, and R. D. Herbert are funded by Australian National Health and Medical Research Council Fellowships. Lesley Gillespie, trial search coordinator of the Cochrane Bone, Joint and Muscle Trauma Group Field, was most helpful in providing updated search results, and Clare Roberston provided valuable comments on the draft manuscript. Elizabeth Barraclough and Sandra O'Rourke provided valuable assistance with data checking, as did Esther Vance with literature searching.

Conflict of Interest: The editor in chief has reviewed the conflict of interest checklist provided by the authors and has determined that the authors have no financial or any other kind of personal conflicts with this manuscript.

Author Contributions: C. Sherrington participated in protocol development, literature searching, data extraction, data analysis, and manuscript preparation. J. C. Whitney participated in protocol development, literature searching, data extraction, and manuscript preparation. S. R. Lord and J. C. T. Close participated in protocol development, data extraction, data analysis, and manuscript preparation. R. D. Herbert participated in protocol development, literature searching, data extraction, data analysis, and manuscript preparation. R. G. Cumming participated in protocol development, data analysis, and manuscript preparation.

Sponsor's Role: None.

REFERENCES

1. Lord SR, Ward JA, Williams P et al. An epidemiological study of falls in older community-dwelling women: The Randwick Falls and Fractures Study. Aust J Public Health 1993;17:240–245.
2. Cripps R, Carman J. Falls by the Elderly in Australia Trends and Data for 1988. Adelaide, Australia: Australian Institute of Health and Welfare, 2001.
3. Campbell AJ, Borrie MJ, Spears GF et al. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. Age Ageing 1990;19:136–141.
4. Clinical Guideline 21. Falls: The Assessment and Prevention of Falls in Older People. London, UK: National Institute for Clinical Excellence, 2004.
5. Ganz DA, Bao Y, Shekelle PG et al. Will my patient fall? JAMA 2007;297:77–86.
6. Gillespie LD, Gillespie WJ, Robertson MC et al. Interventions for preventing falls in elderly people. Cochrane Database Syst Rev 2003;Issue 4.
7. Chang JT, Morton SC, Rubenstein LZ et al. Interventions for the prevention of falls in older adults: Systematic review and meta-analysis of randomized clinical trials. BMJ 2004;328:680.
8. Hayden JA, van Tulder MW, Tomlinson G. Systematic review: Strategies for using exercise therapy to improve outcomes in chronic low back pain. Ann Intern Med 2005;142:776–785.
9. Higgins J, Green S. Cochrane Handbook for Systematic Reviews of Interventions 4.2.5 [Updated May 2005]. The Cochrane Library, Issue 3, 2005. Chichester, UK: John Wiley & Sons Ltd., 2005.
10. Li F, Harmer P, Fisher KJ et al. Tai Chi and fall reductions in older adults: A randomized controlled trial. J Gerontol A Biol Sci Med Sci 2005;60A:187–194.
11. Hannan PJ, Murray DM, Jacobs DR Jr. et al. Parameters to aid in the design and analysis of community trials: Intraclass correlations from the Minnesota Heart Health Program. Epidemiol 1994;5:88–95.
12. Elley CR, Kerse N, Chondros P et al. Intraclass correlation coefficients from three cluster randomized controlled trials in primary and residential health care. Aust NZ J Public Health 2005;29:461–467.
13. Higgins JP, Thompson SG, Deeks JJ et al. Measuring inconsistency in meta-analyses. BMJ 2003;327:557–560.
14. Sterne J, Bradburn M, Egger M. Meta-analysis in Stata. In: Egger M, Smith G, Altman D, eds. Systematic Reviews in Health Care: Meta-Analysis in Context. London: BMJ Publishing Group, 2001, pp 347–369.
15. Williams JG, Higgins JP, Brayne CE. Systematic review of prevalence studies of autism spectrum disorders. Arch Dis Childhood 2006;91:8–15.
16. Moher D, Cook DJ, Eastwood S et al. Improving the quality of reports of meta-analyses of randomized controlled trials: The QUOROM statement. Quality of Reporting of Meta-analyses. Lancet 1999;354:1896–1900.
17. Province MA, Hadley EC, Hornbrook MC et al. The effects of exercise on falls in elderly patients. A preplanned meta-analysis of the FICSIT trials. Frailty and injuries: Cooperative studies of intervention techniques. JAMA 1995;273:1341–1347.
18. Robertson MC, Campbell AJ, Gardner MM et al. Preventing injuries in older people by preventing falls: A meta-analysis of individual-level data. J Am Geriatr Soc 2002;50:905–911.
19. van Peppen RP, Hendriks HJ, van Meeteren NL et al. The development of a clinical practice stroke guideline for physiotherapists in the Netherlands: A systematic review of available evidence. Disabil Rehabil 2007;29:767–783.
20. Murphy MH, Nevill AM, Murtagh EM et al. The effect of walking on fitness, fatness and resting blood pressure: A meta-analysis of randomized, controlled trials. Prev Med 2007;44:377–385.
21. Skelton D, Dinan S, Campbell M et al. Tailored group exercise (Falls Management Exercise—FaME) reduces falls in community-dwelling older frequent fallers (an RCT). Age Ageing 2005;34:636–639.

22. Woo J, Hong A, Lau E et al. A randomized controlled trial of Tai Chi and resistance exercise on bone health, muscle strength and balance in community-living elderly people. Age Ageing 2007;36:262–268.
23. Moreland JD, Richardson JA, Goldsmith CH et al. Muscle weakness and falls in older adults: A systematic review and meta-analysis. J Am Geriatr Soc 2004;52:1121–1129.
24. Orr R, Raymond J, Fiatarone Singh M. Efficacy of progressive resistance training on balance performance in older adults: A systematic review of randomized controlled trials. Sports Med 2008;38:317–343.
25. Latham N, Anderson C, Bennett D et al. Progressive resistance strength training for physical disability in older people. Cochrane Database Syst Rev 2003;Issue 2.
26. 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.
27. Singh NA, Stavrinos TM, Scarbek Y et al. A randomized controlled trial of high versus low intensity weight training versus general practitioner care for clinical depression in older adults. J Gerontol A Biol Sci Med Sci 2005;60A: 768–776.
28. Thompson SG, Higgins JP. How should meta-regression analyses be undertaken and interpreted? Stat Med 2002;21:1559–1573.
29. Robinson W. Ecological correlations and the behaviour of individuals. Am Sociol Rev 1950;15:351–357.
30. Barnett A, Smith B, Lord SR et al. Community-based group exercise improves balance and reduces falls in at-risk older people: A randomized controlled trial. Age Ageing 2003;32:407–414.
31. Bunout D, Barrera G, Avendanõ M et al. Results of a community-based weight-bearing resistance training programme for healthy Chilean elderly subjects. Age Ageing 2005;34:80–83.
32. 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;52A: M218–M224.
33. Campbell AJ, Robertson MC, Gardner MM et al. Randomized controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. BMJ 1997;315:1065–1069.
34. Campbell AJ, Robertson MC, Gardner MM et al. Psychotropic medication withdrawal and a home-based exercise program to prevent falls: A randomized, controlled trial. J Am Geriatr Soc 1999;47:850–853.
35. Campbell AJ, Robertson MC, La Grow SJ et al. Randomized controlled trial of prevention of falls in people aged $\geq$75 with severe visual impairment: The VIP trial. BMJ 2005;331:817.
36. Carter ND, Khan KM, McKay HA et al. Community-based exercise program reduces risk factors for falls in 65- to 75-year-old women with osteoporosis: Randomized controlled trial. Can Med Assoc J 2002;167:997–1004.
37. Cerny K, Blanks R, Mohamed O et al. The effect of a multidimensional exercise program on strength, range of motion, balance and gait in the well elderly [abstract]. Gait Posture 1998;7:185–186.
38. Day L, Fildes B, Gordon I et al. Randomized factorial trial of falls prevention among older people living in their own homes. BMJ 2002;325:128.
39. Ebrahim S, Thompson PW, Baskaran V et al. Randomized placebo-controlled trial of brisk walking in the prevention of postmenopausal osteoporosis. Age Ageing 1997;26:253–260.
40. Faber MJ, Bosscher RJ, Chin APMJ et al. Effects of exercise programs on falls and mobility in frail and pre-frail older adults: A multicenter randomized controlled trial. Arch Phys Med Rehab 2006;87:885–896.
41. Green J, Forster A, Bogle S et al. Physiotherapy for patients with mobility problems more than 1 year after stroke: A randomized controlled trial. Lancet 2002;359:199–203.
42. Hauer K, Rost B, Rutschle K et al. Exercise training for rehabilitation and secondary prevention of falls in geriatric patients with a history of injurious falls. J Am Geriatr Soc 2001;49:10–20.
43. Korpelainen R, Keinanen-Kiukaanniemi S, Heikkinen J et al. Effect of impact exercise on bone mineral density in elderly women with low BMD: A population-based randomized controlled 30-month intervention. Osteoporosis Int 2006;17:109–118.
44. Latham NK, Anderson CS, Lee A et al. A randomized, controlled trial of quadriceps resistance exercise and vitamin D in frail older people: The Frailty Interventions Trial in Elderly Subjects (FITNESS). J Am Geriatr Soc 2003;51:291–299.
45. Lin M-R, Wolf SL, Hwang H-F et al. A randomized, controlled trial of fall prevention programs and quality of life in older fallers. J Am Geriatr Soc 2007;55:499–506.
46. Lord SR, Ward JA, Williams P et al. 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.
47. Lord SR, Castell S, Corcoran J et al. The effect of group exercise on physical functioning and falls in frail older people living in retirement villages: A randomized, controlled trial. J Am Geriatr Soc 2003;51:1685–1692.
48. Liu-Ambrose T, Khan KM, Eng JJ et al. Resistance and agility training reduce fall risk in women aged 75 to 85 with low bone mass: A 6-month randomized, controlled trial. J Am Geriatr Soc 2004;52:657–665.
49. Luukinen H, Lehtola S, Jokelainen J et al. Pragmatic exercise-oriented prevention of falls among the elderly: A population-based, randomized, controlled trial. Prev Med 2007;44:265–271.
50. McMurdo ME, Mole PA, Paterson CR. Controlled trial of weight bearing exercise in older women in relation to bone density and falls. BMJ 1997;314:569.
51. Madureira MM, Takayama L, Gallinaro AL et al. Balance training program is highly effective in improving functional status and reducing the risk of falls in elderly women with osteoporosis: A randomized controlled trial. Osteoporosis Int 2007;18:419–425.
52. Means KM, Rodell DE, O'Sullivan PS. Balance, mobility, and falls among community-dwelling elderly persons: Effects of a rehabilitation exercise program. Am J Phys Med Rehabil 2005;84:238–250.
53. Morgan RO, Virnig BA, Duque M et al. Low-intensity exercise and reduction of the risk for falls among at-risk elders. J Gerontol Series A Biol Sci Med Sci 2004;59A:1062–1067.
54. 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.
55. Nowalk MP, Prendergast JM, Bayles CM et al. A randomized trial of exercise programs among older individuals living in two long-term care facilities: The Falls FREE program. J Am Geriatr Soc 2001;49:859–865.
56. Protas EJ, Mitchell K, Williams A et al. Gait and step training to reduce falls in Parkinson's disease. Neurorehabilitation 2005;20:183–190.
57. Reinsch S, MacRae P, Lachenbruch PA et al. Attempts to prevent falls and injury: A prospective community study. Gerontologist 1992;32: 450–456.
58. Resnick B. Testing the effect of the WALC intervention on exercise adherence in older adults. J Gerontol Nurs 2002;28:40–49.
59. Robertson MC, Devlin N, Gardner MM et al. Effectiveness and economic evaluation of a nurse delivered home exercise programme to prevent falls. 1: Randomised controlled trial. BMJ 2001;322:697–701.
60. 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 A Biol Sci Med Sci 2000;55A:M317–M321.
61. Sakamoto K, Nakamura T, Hagino H et al. Effects of unipedal standing balance exercise on the prevention of falls and hip fracture among clinically defined high-risk elderly individuals: A randomized controlled trial. J Orthopaedic Sci 2006;11:467–472.
62. Schoenfelder DP. A fall prevention program for elderly individuals. Exercise in long-term care settings. J Gerontol Nurs 2000;26:43–51.
63. Schnelle JF, Kapur K, Alessi C et al. Does an exercise and incontinence intervention save healthcare costs in a nursing home population? J Am Geriatr Soc 2003;51:161–168.
64. Sihvonen S, Sipila S, Taskinen S et al. Fall incidence in frail older women after individualized visual feedback-based balance training. Gerontology 2004;50:411–416.
65. Steinberg M, Cartwright C, Peel N et al. A sustainable programme to prevent falls and near falls in community dwelling older people: Results of a randomized trial. J Epidemiol Community Health 2000;54:227–232.
66. Suzuki T, Kim H, Yoshida H et al. Randomized controlled trial of exercise intervention for the prevention of falls in community-dwelling elderly Japanese women. J Bone Miner Metab 2004;22:602–611.
67. Toulotte C, Fabre C, Dangremont B et al. Effects of physical training on the physical capacity of frail, demented patients with a history of falling: A randomized controlled trial. Age Ageing 2003;32:67–73.
68. Voukelatos A, Cumming RG, Lord SR et al. A randomized, controlled trial of tai chi for the prevention of falls: The Central Sydney Tai Chi Trial. J Am Geriatr Soc 2007;55:1185–1191.
69. Wolf SL, Barnhart HX, Kutner NG et al. Reducing frailty and falls in older persons: An investigation of Tai Chi and computerized balance training. Atlanta FICSIT Group. Frailty and Injuries: Cooperative Studies of Intervention Techniques. J Am Geriatr Soc 1996;44:489–497.
70. Wolf SL, Sattin RW, Kutner M et al. Intense tai chi exercise training and fall occurrences in older, transitionally frail adults: A randomized, controlled trial. J Am Geriatr Soc 2003;51:1693–1701.
71. Maher CG, Sherrington C, Herbert RD et al. Reliability of the PEDro scale for rating quality of randomized controlled trials. Phys Ther 2003;83: 713–721.