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ORIGINAL ARTICLE

A multi-component exercise regimen to prevent functional decline and bone fragility in home-dwelling elderly women: randomized, controlled trial

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Abstract
Summary This study showed that combination of strength, balance, agility and jumping training prevented functional decline and bone fragility in home-dwelling elderly women. The finding supports the idea that it is possible to maintain good physical functioning by multi-component exercise program and thus postpone the age-related functional problems.
Introduction This 1-year randomized, controlled exercise intervention trial assessed the effects of two different training programs and their combination on physical functioning and bone in home-dwelling elderly women.
Methods One hundred and forty-nine healthy women aged 70–78 years were randomly assigned into: group 1—resistance training (RES), group 2—balance-jumping training (BAL), group 3—combination of resistance and balance-jumping training (COMB), and group 4—controls (CON). Self-rated physical functioning, leg extensor force, dynamic balance, and bone mass and structure were measured.
Results Self-rated physical functioning improved in the COMB group, but was reduced in the CON group; the mean inter-group difference was 10% (95% CI: 0–22%). Mean increase in the leg extensor force was higher in the RES (14%; 4–25%) and COMB (13%; 3–25%) compared with the CON groups. Dynamic balance improved in the BAL (6%; 1–11%) and in the COMB (8%; 3–12%) groups. There were no inter-group differences in BMC at the proximal femur. In those COMB women who trained at least twice a week, the tibial shaft structure weakened 2% (0–4%) less than those in the CON group.
Conclusions Strength, balance, agility, and jumping training (especially in combination) prevented functional decline in home-dwelling elderly women. In addition, positive effects seen in the structure of the loaded tibia indicated that exercise may also play a role in preventing bone fragility.

Keywords Balance training · Bone fragility · Bone strength · Functional decline · Osteoporosis · Strength training

These data were presented in part at the American Society for Bone and Mineral Research meeting held in Seattle, Washington on 1–5 October 2004 and at the 18th Congress of the International Association of Gerontology held in Rio de Janeiro, Brazil on 26–30 June 2005.

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Introduction

Proper physical functioning and ambulation are essential determinants of quality of life among home-dwelling elderly people. Functional decline predisposes to the need for home services and hospitalization [1, 2] and impaired mobility is an

independent predictor of falls and fall-induced injuries (fractures) in older adults [3–5]. In addition, in conjunction with risk factors for falling, decreased bone strength attributable to osteopenia or osteoporosis is associated with their low-energy fractures [6]. Thus, there is a need to develop and test efficient, safe, and feasible ways to prevent functional decline and bone loss among elderly persons.

Exercise has been shown to be an effective method of preventing falls in elderly individuals [7, 8], especially when balance and strength training are combined [8]. There is also evidence that aerobics, weight-bearing, and resistance exercises have positive effects on bone mineral density (BMD) of the spine, as does walking on the hip BMD among postmenopausal 45- to 70-year-old women [9], but data are sparse in women over 70 years of age, especially those concerned with bone structure. It seems quite evident that exercise that focuses primarily on improving underlying impairments in balance, muscle strength, and mobility can prevent functional decline [10–12]. However, the study participants have typically been frail, with reduced physical function, low bone mass, and previous falls and fractures. Therefore, it is also important to study whether exercise can prevent functional decline and bone loss in healthy, home-dwelling elderly people—perhaps the most profitable target population in terms of primary prevention. In other words, the key research questions are whether it is possible to maintain good physical functioning and bone health among these people by physical training, and thus postpone the age-related functional decline, and, if so, is it then crucial to train balance, or muscle strength of lower limbs, or both?

The purpose of this 1-year randomized, controlled exercise intervention trial was to evaluate separately the specific effects of resistance training, balance-jumping training, and their combination on physical functioning and bone strength in home-dwelling 70- to 79-year-old women.

Materials and methods

Design

The study was a randomized controlled trial with four experimental groups:

1. A resistance training group (RES)
2. A balance-jumping training group (BAL)
3. A combination group doing resistance training and balance-jumping training (COMB)
4. A non-training control group (CON)

The assigned training frequency was three times a week for 12 months. All measurements were done at baseline (before the intervention) and at the end of the 12-month intervention.

Participants

The trial profile is presented in Fig. 1. First, a questionnaire was sent to a random population sample (n=40,32) of 70- to 79-year-old women living in the city of Tampere, Finland, inquiring whether they were interested in participating this randomized, controlled exercise intervention study of elderly women. A total of 2,706 women responded and 858 expressed their initial interest. Two hundred and forty-one eligible women were then invited to a screening examination, and 149 of them met the inclusion criteria (see below). According to a computer-generated randomization list, 37 women were assigned to the RES group, 37 women to the BAL group, 38 women to the COMB group, and 37 women to the CON group. A computer-generated randomization list was drawn up by the statistician (MP), who was blinded to the study participants and their characteristics, and randomly allocated participants into four groups (simple randomization).

The inclusion criteria were: willingness to participate, age between 70 and 79 years, a full understanding of the study procedures, no history of any illness contraindicating exercise or limiting participation in the exercise program, no history of any illness affecting balance or bones, no uncorrected vision problems, and not taking medications known to affect balance or bone metabolism (for 12 months before the enrolment). A participant was excluded if she was involved in intense exercise more than twice a week or the T-score for femoral neck bone mineral density (BMD) was lower than −2.5 (i.e., indicating osteoporosis and subsequent medical attention).

The baseline characteristics of the participants are given in Table 1. The study was approved by the Ethics Committee of the Pirkanmaa Hospital District. All participants gave their written informed consent prior to the study.

Training programs

The exercise training classes were arranged 3 times a week for 12 months. Each class included a warm-up of 7–10 min, 25–30 min of effective training (see descriptions below) and an 8- to 10-min period for cooling down. All classes were supervised by exercise leaders of the UKK Institute, who had been trained to supervise these special training programs before the trial began. They also kept an attendance record for each of the participants.

Resistance training

The RES group accustomed themselves to resistance training for 6 weeks. During the first weeks the participants became familiar with the equipment. Then the instructors assessed the participants' training loads

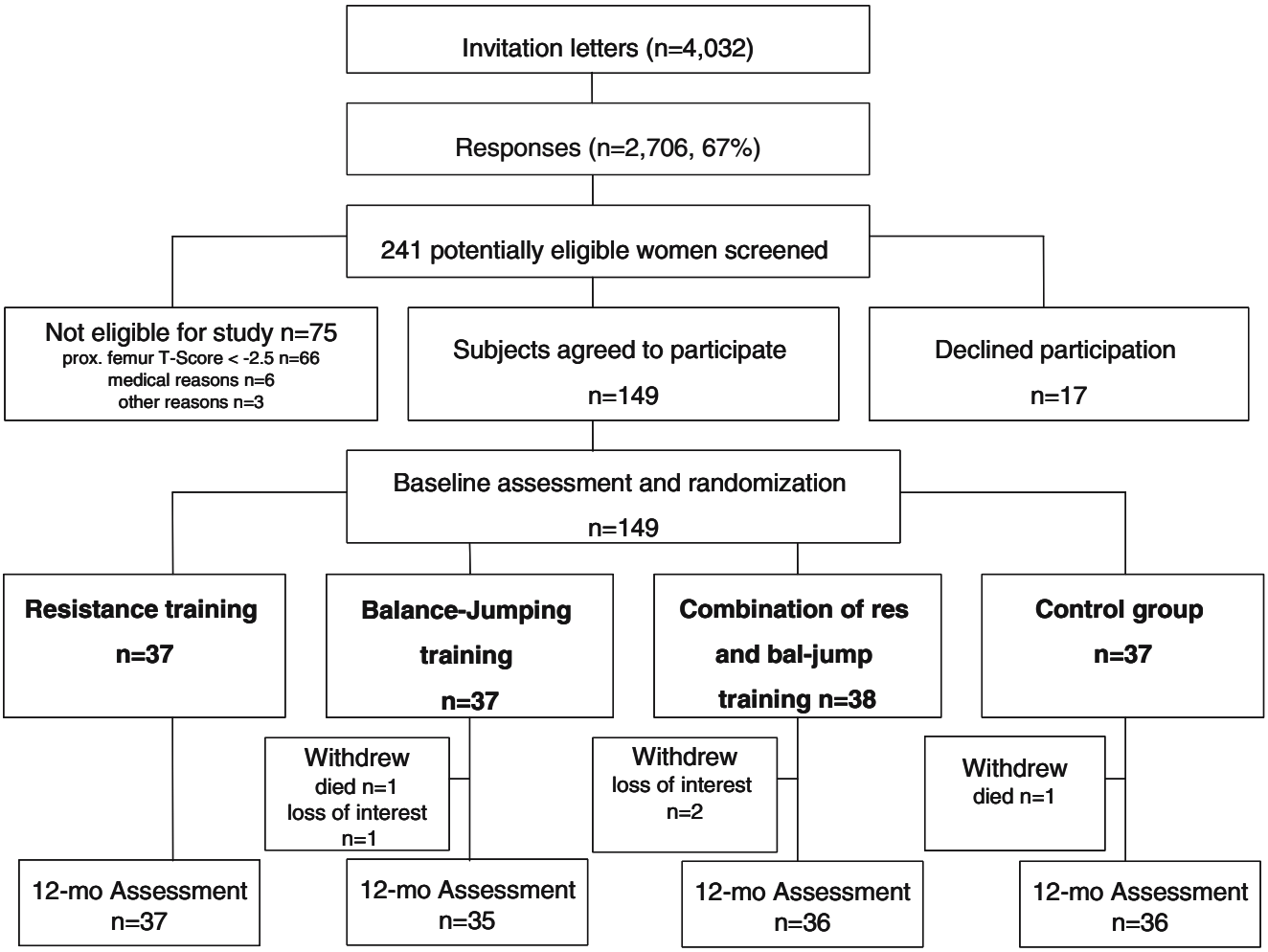

Fig. 1 Trial profile

and taught them the individually tailored resistance training program. The intensity of training stimulus was set at 50–60% of one repetition maximum (1RM) using 2 sets and 10–15 repetitions. Thereafter, the intensity progressed to 75–80% of 1RM with work range of 3 sets and 8–10 repetitions. The intensity was assessed using rated perceived exertion (RPE). If the RPE dropped below 18 (maximum 20) the participants were asked to increase load (about 5%) or repetitions. A two-min recovery was provided between the training sets and each set of repetitions. The program included large muscle group exercises, such as raising from a chair using a weight vest, squatting, leg presses, hip abduction, hip extension, calf rise, and rowing using resistance training machines. To prevent the programs being too monotonous, five different combinations of the above-mentioned exercises in 10-week periods were used during the intervention.

Balance-jumping training

The primary training components in the BAL group were balance, agility, and impact exercise. In detail, training classes included static and dynamic balance and agility training sessions, jumps and other impacts, and changes of direction exercises (such as acceleration and deceleration back and forth, and sideways walking with stops and turns) with music. Some of the exercises were done with a step-board. During the first 6 weeks, the trainees accustomed themselves to the balance and agility training. Thereafter, the degree of difficulty of movements, steps, impacts, and jumps was gradually increased. The type of training was modified aerobics or step aerobics alternating every 2 weeks (2 weeks' aerobics, 2 weeks' step aerobics) in 12-week periods. There were four different aerobics and step aerobics programs with different combinations of the above noted balance-jumping movements during the intervention.

Table 1 Group characteristics at baseline

Variable	RES[a] n=37	BAL[b] n=37	COMB[c] n=38	CON[d] n=37
Age, mean (SD)	72.7 (2.5)	72.9 (2.3)	72.9 (2.2)	72.0 (2.1)
Height, cm, mean (SD)	160.5 (4.8)	159.0 (6.1)	159.1 (5.3)	158.4 (5.8)
Weight, kg, mean (SD)	74.3 (11.0)	70.9 (9.6)	69.4 (10.6)	74.3 (10.8)
BMI, kg/m^2, mean (SD)	28.8 (4.0)	28.0 (3.2)	27.5 (4.2)	29.6 (3.7)
Calcium intake, mg/day, mean (SD)	940 (365)	960 (331)	916 (302)	894 (264)
Physical activity/week, *n* (%)				
None or some	19 (51.4)	16 (43.2)	15 (39.5)	17 (45.9)
Brisk exercise 1×	8 (21.6)	8 (21.6)	9 (23.7)	9 (24.3)
Brisk exercise 2×	10 (27.0)	13 (35.1)	14 (36.8)	11 (29.7)
Chronic diseases and symptoms, *n* (%)				
Hypertension	6 (16.2)	12 (32.4)	10 (26.3)	13 (35.1)
Hyperlipidemia	3 (8.1)	8 (21.6)	5 (13.2)	9 (24.3)
Hypo-/hyperthyroidism	5 (13.5)	2 (5.4)	2 (5.3)	9 (24.3)
Arthritis/joint pain	3 (8.1)	4 (10.8)	2 (5.3)	3 (8.1)

[a] Resistance training group
[b] Balance-jumping training group
[c] Combination of resistance and balance-jumping training group
[d] Control group

Combination of resistance and balance-jumping training

The COMB training consisted of the above described resistance and balance-jumping training on alternate weeks. In addition to the 6-week familiarizing periods, two different resistance training and two different balance-jumping training programs were performed during the entire intervention.

Control group

The controls were asked to maintain their pre-study level of physical activity during the 12-month trial.

Questionnaires

General health and habitual physical activity were assessed by a questionnaire at baseline. A health questionnaire addressed medical conditions, current medications, years of menopausal estrogen therapy, history of fractures, and current physical activity in leisure time.

All participants reported their health status and physical activity (type, frequency, and duration) monthly during the intervention. Reported weekly physical activity was converted to MET (metabolic equivalent) hours/week [13].

Dietary intake and possible use of vitamin and mineral supplements were assessed by a complete 3-day (2 weekdays and a Sunday) food record at baseline and at the end, and calculated by Micro-Nutrica software (Social Insurance Institution, Helsinki, Finland).

Physical functioning

Physical performance tests

Dynamic balance and agility was tested by a standardized figure-of-8 running test around two poles placed 10 m apart [14, 15]. The participant was asked to run or walk two laps of the course as fast as possible. The running time was measured using a stop-watch. The best attempt of two trials was recorded. The maximal isometric leg extension force was measured with a leg press dynamometer (Tamtron, Tampere, Finland) at a knee angle of 90° with precision of about 5% [16].

Self-rated physical functioning

Self-rated physical functioning was assessed with the standardized Finnish Physical Functioning Scale of the Rand 36-Item Health Survey [17, 18]. The participants filled in the questionnaire at home and it was checked together with the participant during her visit for the physical performance tests. The Scale comprises 10 questions on coping with daily activities, such as running, lifting heavy things, climbing stairs of several floors, and walking half a kilometer. Each item is scored either to major restricts (0 points), minor restricts (50 points) or no restrict (100 points). An individual Physical Functioning Index score is the mean of scores of all answered items. In the case of no reply to more than 5 items, no Index score was calculated. In a Finnish population sample for standardization aged 18–79 years the homogeneity, i.e., the mean of the item intercorrelations of the Scale, was 0.63 and Cronbach alpha 0.94 [18].

Bone measurements

Bone mineral density and content (BMD and BMC) of the right proximal femur were measured with dual-energy X-ray absorptiometry (DXA, Norland XR-26; Norland, Fort Atkinson, WI, USA) according to our standard procedures with in vivo precision of about 1% [19]. Femoral neck BMD was used for the screening of the study participants,

while BMC of the femoral neck (divided by the height of the neck region) was used as the primary outcome.

In addition to BMC assessment, the gross structure of the narrowest femoral neck section was analyzed using the hip structure analysis (HSA) [20]. In this study, section modulus (Z; as an index of bending strength) and periosteal diameter were used. The in vivo precision of these measurements was 4.8% and 2.5% respectively [21].

The peripheral quantitative computed tomography (pQCT; XCT 3000; Stratec Medizintechnik, Pforzheim, Germany) were performed at the distal sites (trabecular bone), and at midshaft (cortical bone) of the right radius and tibia according to our standard procedures [22]. For the distal sites, trabecular density (TrD), and density-weighted polar section modulus (BSI, an index of torsion bending strength) were used, while the cortical area (CoA), cortical density (CoD), and BSI were used for the shaft sites. In our laboratory, the in vivo precision ranges from 0.7% (tibial shaft CoD) to 7.7% (distal radius BSI) [22].

Statistical analyses

Means and standard deviations (SD) were used as descriptive statistics. Primary outcome variables were self-rated physical functioning, physical performance (balance and lower limbs muscle force), and bone mass and structure.

All results were based on the Intention-To-Treat analyses (ITT) of all available participants. In addition to the ITT analyses, efficacy or per protocol analyses of the exercise were carried out for the self-rated physical functioning, physical performance, and bone variables. The inclusion criterion for this active exercise group was the average training frequency at least twice a week during the trial.

Changes in weight, height, and calcium intake were analyzed with a paired sample *t* test. Analysis of covariance (ANCOVA) with 12-month measurements as dependent variables was used to assess the treatment effect between the exercise and control groups. Baseline values, age, and time interval between measurements were used as covariates. Post hoc between-groups comparisons were performed using Sidak's adjustment for multiple comparisons. Due to the skewed distributions in some outcome variables and to obtain the relative between-group differences, log-transformed variables of outcome were used in the ANCOVA. Geometric mean ratios and their 95% confidence intervals (CI) were calculated as antilog of difference in group means at end of the 12-month intervention. All data were analyzed using SPSS 11.5 statistical software.

Preliminary power calculations focusing on dynamic balance (figure-of-8 running test) as the outcome variable indicated that at α level of 0.05 and common standard deviation of 10% for the change during the intervention, a sample size of 70 women in each group would give 80% power for the study to detect a 5% treatment effect in dynamic balance between the groups. The actual number of participants in each group was 37 (in 3 groups) and 38 (in 1 group) at the onset of the study. If necessary, for the sake of statistical power, it was decided that groups that had resistance training components (RES and COMB, n=75) and groups that had balance-jumping training components (BAL and COMB, n=75) could be combined to provide adequate groups for determining the effect of resistance training or balance-jumping training by comparing them with the pooled group of the remaining participants.

Results

Descriptive characteristics

Baseline clinical characteristics for the study groups are given in Table 1. There were no differences among the groups. The participants in all the groups had a similar history of hormone replacement therapy [23]. There were no changes in height or calcium intake during the intervention. Weight (mean, 95% CI) decreased at least slightly in all groups, but significantly in the BAL group (−0.76 kg, −1.46 to −0.07, p=0.033) and in the COMB group (−0.94 kg, −1.80 to −0.09, p=0.031). The mean duration of moderate non-intervention physical activity (4.5 MET) during the intervention was 5 (SD 3) h per week in the RES and BAL groups and 7 (SD 4) h per week in the COMB and CON groups. During the intervention period there were 8 falls in the RES, 18 falls in the BAL, 19 falls in the COMB, and 13 falls in the CON groups. Two members of the RES group and one of the CON group suffered a radius fracture. Also, one of the controls suffered a fracture of a toe. There were no statistically significant differences among the groups.

Program feasibility

The drop-out rate was 3.4%. There were four drop-outs in the training groups and one in the control group. Figure 1 shows the reasons for withdrawal. Mean training compliance, measured as attendance at all offered training sessions, was 67% (range 0 to 100%), being highest in the RES group (74%), followed by the COMB group (67%), and the BAL group (59%). Twenty-nine women (78%) in the RES, 25 (66%) in the COMB, and 22 (59%) in the BAL group trained an average of at least twice a week (and were included in the efficacy analysis).

During the intervention, 14 participants from the training groups consulted the attending physician due to musculoskeletal injuries or symptoms (1 ligament injury of the knee, 2 minor knee injuries, 1 partial rupture of the

quadriceps femoris muscle, and 10 participants had overuse symptoms). In addition, 1 participant was taken to the emergency unit due to acute low back pain. Three of them did not return to the training classes, but they participated in the 12-month measurements and were included in the analyses according to the ITT principle. Four exercisers (two in the BAL and two in the COMB groups) fell during supervised intervention exercise, but returned to the training classes within 2 weeks. Altogether, there were no differences in the numbers of monthly reported health problems between exercisers and controls (p=0.955).

Physical functioning

Physical performance

The absolute values of the physical performance at baseline and after 12 months are shown in Table 2. After the 12-month trial, the mean gain in isometric leg extension force was statistically significantly greater in the RES group (effect: 14%, 95% CI: 4–25%) and in the COMB group (13%; 2–25%) compared with the CON group. In addition, the figure-of-8 running time improved significantly more in the BAL group (6%; 1–11%) and in the COMB group (8%; 3–12%) compared with the CON group (Fig. 2).

In the efficacy analysis, the above-noted significant between-group differences in leg extension force were enhanced (Fig. 2). In addition, the dynamic balance change was significantly higher in the BAL group (5%; 1–10%) and in the COMB group (5%; 0–10%) compared with the RES group.

Self-rated physical functioning

The Index score could be calculated for 99% of the total group (n=148) at baseline and for 95% of those who participated in the assessments at 12 months (n=142). Cronbach alpha was 0.76 and the mean inter-item correlation 0.25 at baseline. After 12 months, the corresponding values were 0.80 and 0.30. In all groups, the distributions of the item scores and the Index score clearly accumulated to the high values, thus indicating good physical functioning. At baseline, 10% (n=14) of the participants scored 100, the maximum value of the Index. The mean baseline Index score for the total group (82.7, SD 13.0) was significantly higher (p<0.001) than the means observed in the standardized population samples aged 75–79 years (mean 45.1, SD 28.4) and 70–74 years (mean 54.1, SD 27.8) [16].

After 12 months, minor changes in the Index score means were observed in the COMB (+3.5), RES (+1.4), and CON (−1.7) groups (Table 2). A significant treatment effect was found between the COMB and CON groups (effect: 10%; 95% CI: 0–22%; Fig. 2). The efficacy analyses indicated the mean benefit of 12% (0–26%) in the BAL group and 11% (−1–+24%) in the COMB group compared with the CON group (Fig. 2).

Bone measurements

The observed bone values at baseline and after 12 months are shown in Table 2. The ITT analysis did not show any significant treatment effect at the femoral neck BMC, while there was a significant effect on the section modulus (Z) of the femoral neck between RES and COMB (effect: 5%; 95% CI: 0–9%; due to technical limitations this analysis could be performed in 124 of the 144 measured participants; Fig. 3). However, this effect on Z did not reach statistical significance in the efficacy analysis.

In the pQCT variables, there were no significant between-group differences in the ITT analysis of the distal or midshaft sites of the tibia or radius. In the efficacy analysis, in turn, tibial shaft bone strength index (BSI) decreased 2% (0–4%) less in the COMB group than in the CON group (Fig. 3). In addition, there was a trend suggesting that training could be beneficial for the tibial shaft cortical area and the distal tibia BSI.

Discussion

This 12-month randomized, controlled intervention study showed a significant increase in self-rated physical functioning, dynamic balance, and isometric muscle force of the lower limbs among 70- to 78-year-old healthy women as a response to the combined resistance and balance-jumping training. As could be expected, resistance training improved muscle force and balance-jumping training improved dynamic balance. Further, positive effects of combined training were seen at the structure of the loaded tibia. Although exercise did not increase femoral neck bone mass, a treatment effect in the femoral neck structure was observed between the training groups, as judged from the DXA-derived section modulus data.

In our study, the effects of exercise were task-specific in terms of muscle force and balance. Consequently, the resistance training increased muscle force, but did not alter dynamic balance, while balance-jumping training improved balance without any statistically significant improvement in lower limb force, and importantly, the combined training improved both muscle force *and* balance characteristics. These results are consistent with Wolfson et al. [24], who did not find a clear overlapping effect of balance and strength training among healthy elderly individuals. In contrast to our findings, Nelson et al. [25] found that high-intensity strength training twice a week could also improve balance, estimated by backward tandem walking, among

Table 2 Observed baseline and 12-month values of physical functioning and bone variables (mean and SD)

Variable		RES	BAL	COMB	CON
Self-rated physical functioning					
(0–100)	Baseline	83.4 (11.7)	84.6 (12.0)	82.5 (14.9)	82.0 (12.4)
	12 months	84.8 (12.5)	84.7 (11.5)	86.0 (13.6)	80.3 (16.4)
Physical performance					
Leg press, N/kg	Baseline	16.2 (3.5)	16.5 (3.6)	16.6 (4.0)	16.1 (2.5)
	12 months	20.2 (4.6)	19.6 (4.3)	20.2 (4.4)	17.6 (2.8)
Figure-of-8 running time, s	Baseline	20.7 (3.2)	20.6 (2.9)	21.0 (3.2)	20.0 (2.6)
	12 months	20.0 (3.2)	19.4 (3.0)	19.3 (2.2)	20.0 (2.8)
Bone health					
Femoral neck					
BMC, g	Baseline	2.74 (0.35)	2.77 (0.42)	2.68 (0.28)	2.72 (0.45)
	12 months	2.71 (0.33)	2.73 (0.40)	2.65 (0.29)	2.67 (0.44)
Z, mm^3	Baseline	1,431 (238)	1,389 (220)	1,411 (164)	1,395 (259)
	12 months	1,430 (235)	1,386 (239)	1,353 (154)	1,362 (247)
Width, mm	Baseline	32.0 (2.2)	31.7 (2.2)	32.2 (2.2)	31.4 (2.0)
	12 months	32.0 (2.2)	31.6 (2.4)	32.2 (2.1)	31.4 (2.0)
Distal tibia					
TrD, mg/cm^3	Baseline	220 (26)	223 (34)	215 (39)	227 (33)
	12 months	219 (26)	224 (34)	215 (39)	226 (33)
BSI, mm^3	Baseline	796 (313)	867 (251)	750 (325)	888 (306)
	12 mo	781 (310)	870 (247)	741 (324)	862 (307)
Tibial shaft					
CoD, mg/cm^3	Baseline	1,130 (34)	1,120 (31)	1,120 (34)	1,125 (37)
	12 months	1,125 (35)	1,121 (31)	1,118 (34)	1,127 (40)
CoA, mm^2	Baseline	245 (29)	248 (25)	238 (29)	245 (34)
	12 months	245 (29)	246 (25)	237 (30)	241 (33)
BSI, mm^3	Baseline	1,334 (184)	1,329 (197)	1,303 (174)	1,273 (210)
	12 months	1,331 (187)	1,323 (198)	1,297 (177)	1,255 (211)
Distal radius					
TrD, mg/cm^3	Baseline	189 (37)	190 (45)	180 (47)	186 (42)
	12 months	184 (42)	189 (49)	180 (48)	183 (44)
BSI, mm^3	Baseline	232 (99)	246 (70)	217 (75)	256 (85)
	12 months	234 (83)	248 (87)	216 (81)	266 (79)
Radial shaft					
CoD, mg/cm^3	Baseline	1,136 (45)	1,136 (33)	1,131 (40)	1,145 (39)
	12 months	1,135 (40)	1,133 (34)	1,126 (40)	1,143 (37)
CoA, mm^2	Baseline	68.3 (11.4)	69.8 (9.9)	66.6 (10.7)	68.8 (11.4)
	12 months	68.4 (10.7)	69.7 (10.5)	66.5 (11.1)	68.4 (11.5)
BSI, mm^3	Baseline	212 (45)	214 (43)	204 (37)	201 (44)
	12 months	211 (40)	214 (46)	203 (39)	199 (43)

BMC bone mineral content, *Z* section modulus, *TrD* trabecular density, *BSI* bone strength index, *CoD* cortical density, *CoA* cortical area

50- to 70-year-old women. The younger age compared with our participants and different methods of assessing dynamic balance may at least partly explain the inconsistent results.

In addition to improved physical performance per se, the combined resistance and balance-jumping training had a positive effect on self-rated physical functioning. It has been previously shown that a home-based training program including balance and strength exercises can reduce the progression of functional decline among physically frail elderly people living at home [26], especially when underlying impairments in physical abilities are targeted [10]. In contrast to these studies, our participants were healthy. Nevertheless, our regular progressive group-exercise program could maintain, or even improve their initially good physical functioning during the 12 months. This effect was partially attributable to the small age-related decline among controls.

Our results are consistent with a recent nonrandomized exercise study, in which 1-year strength training accompanied by flexibility and body balance exercises, significantly improved not only muscle function, but also functional ability among healthy community-dwelling women aged 75 or over [27]. On the contrary, a recent meta-analysis of progressive resistance training in elderly people did not show any effect on physical disability despite a large positive effect on strength and a modest effect on gait speed

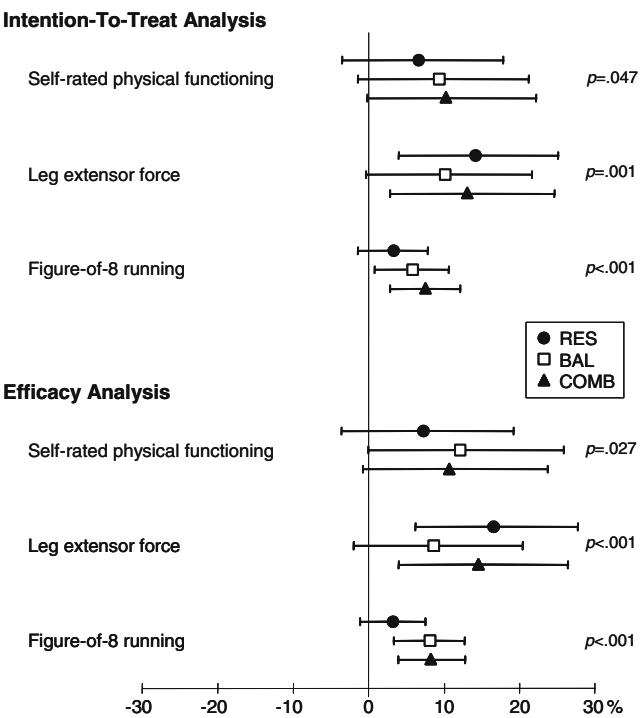

Fig. 2 The adjusted percentage differences of the training participants compared with the controls (mean, 95% CI) after intervention in physical functioning variables using Intention-To-Treat and Efficacy analysis. *RES* resistance training group, *BAL* balance-jumping training group, *COMB* combination training group. Baseline values, age, and time between measurements were used as covariates. *p* Values are for the between-group differences in the ANCOVA (F-test). The 95% CI are Sidak-adjusted

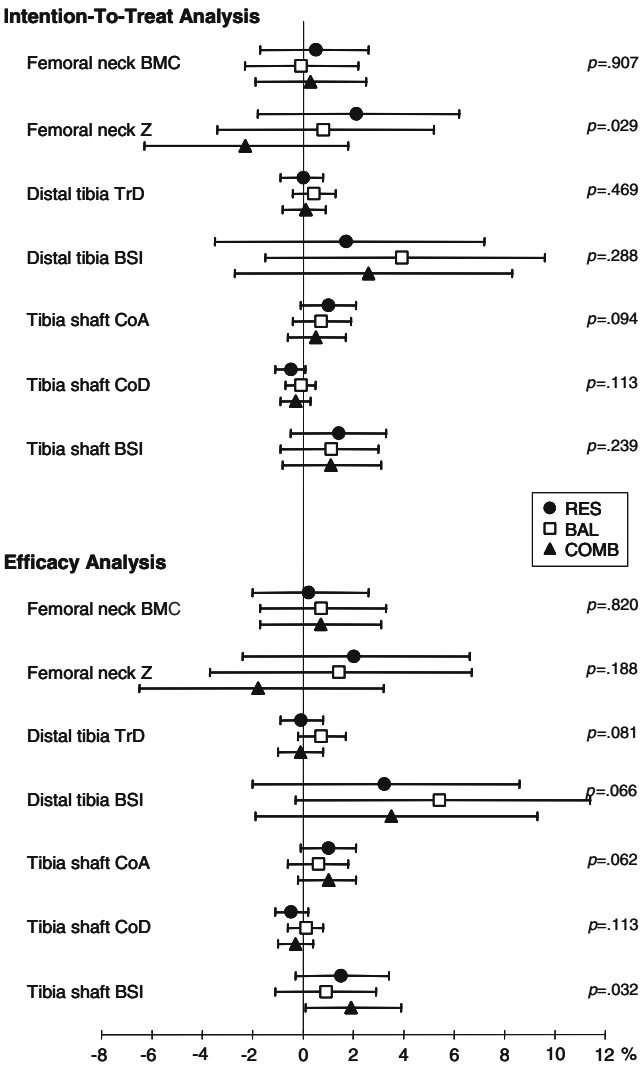

Fig. 3 The adjusted percentage differences of the training participants compared with the controls (mean, 95% CI) after intervention in the lower limb bone structure variables using Intention-To-Treat and Efficacy analysis. *BMC* bone mineral content, *Z* section modulus at the femoral neck, *TrD* trabecular density, *BSI* bone strength index, *CoA* cortical area, *CoD* cortical density. Baseline values, age, and time between measurements were used as covariates. *p* Values are for the between-group differences in ANCOVA (F-test). The 95% CI are Sidak-adjusted

[28]. Moreover, de Vreede and co-workers [29] recently concluded that functional task exercises were more effective than resistance training in improving healthy elderly women's ability to carry on daily tasks. In our study the combined resistance and balance-jumping training was most effective in improving self-rated physical functioning. Simultaneously, significant improvements in body balance and muscle strength of lower limbs were observed in this group. Presumably, the improved body balance and better force of the lower limbs had a positive influence on self-rated physical functioning. Our results thus support the idea that it is possible to maintain or even improve the good baseline physical functioning of elderly women with balance, jumping, and lower limb strength exercises.

Previously, it has been suggested that group-delivered exercise would be less effective than individually prescribed home exercise, especially in fall prevention [8]. However, some group exercise interventions have successfully maintained physical functioning and prevented falls [30, 31]. Our results support the latter, showing that group-based resistance and balance-jumping training can be effective in preventing functional decline in healthy home-dwelling elderly women. In addition, Day et al. [32] have reported that a weekly group-based combined training program, including strength, balance, and flexibility training (supported by small amounts of home exercise) improved body balance and reduced falls in healthy home-dwelling elderly people within 15 weeks.

We did not find any exercise effect on bone mineral mass of the femoral neck in contrast to some studies showing a positive response to exercise at the femoral neck among elderly women [25, 33, 34]. However, some other findings are more consistent with our results, indicating no such exercise effect [15, 35, 36]. Recently, Villareal et al. [37] did not find relatively vigorous multi-component exercise training to increase BMD compared with low intensity exercise in frail elderly persons.

Concerning the findings above and bone strength in general, we should recall, however, that it is more important to see an exercise effect on bone structural strength than on BMD or BMC. Previously, Kaptoge et al. [38] reported that among elderly women hip section modulus was more strongly related to physical activity than BMD. In our study a significant difference in femoral neck section modulus (Z) was observed between the RES and COMB groups, indicating that resistance training might have redistributed bone mineral within the femoral neck and thus strengthened the structure. Probably due to reduced sample size, this effect could not be confirmed by the efficacy analysis, although the trend was similar.

At the tibia, where loading-induced stresses are apparently highest, we observed a strengthening effect of combined training on bone structure among those participants who trained at least twice a week. This finding is consistent with our previous study [15]. Recently, Liu-Ambrose et al. [39] also found that agility training may have positive effects on cortical bone at the tibial shaft of elderly osteoporotic women.

This study has several strengths. First, it was a randomized controlled exercise intervention trial with three different training groups and a control group, and with only very few drop-outs. Second, the training participants did not report more health problems or training-induced injuries compared with the controls during the intervention. Third, the general training compliance was good (67%), although there was variability among the training groups (the highest compliance was in the RES and the lowest in the BAL groups). Perhaps the resistance training was more convenient to participants than the more physically demanding (balance-)jumping training. However, the COMB group also underwent (balance-)jumping training with good compliance. One reason for differences in compliance may be the group size at the training classes: the RES and COMB groups trained in smaller groups (8 to 11 participants) compared with the BAL group (17 to 21). This fact, solely due to practical arrangements, might have enhanced the grouping process, helping participants to get to know each other better, thus creating a positive "pressure" for the group members to attend the training sessions. Despite the strengths of the study, the results cannot be generalized to all elderly women since the participants were clinically healthy and had fairly good self-rated physical functioning, and were therefore capable of exercising vigorously.

Conclusion

Healthy elderly women with initially good physical functioning seem to have a good capacity to prevent age-related functional decline by participating in a progressive group exercise regimen of balance, agility, jumping, and strength training. Positive effects found in the structure of the loaded tibia indicated that exercise may also play a role in preventing bone fragility. In addition, successful completion of the training with a low rate of adverse effects suggested that the training program was feasible for these previously untrained women. These findings may be of great importance regarding prevention of many unwanted long-term consequences of aging and functional decline, such as falls, fall-induced injuries, and premature institutionalization.

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