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ORIGINAL ARTICLE

Effect of impact exercise on bone mineral density in elderly women with low BMD: a population-based randomized controlled 30-month intervention

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Abstract Evidence of the effect of exercise on bone loss comes mainly from studies in voluntary postmenopausal women, and no population-based, long-term interventions have been performed. The purpose of this population-based, randomized, controlled trial was to determine the effect of long-term impact exercise on bone mass at various skeletal sites in elderly women with low bone mineral density (BMD) at the radius and hip. Participants (n = 160) were randomly assigned to 30 months either of supervised and home-based impact exercise training or of no intervention. The primary outcome measures were femoral neck, trochanter and total hip BMD, and the secondary outcomes were bone density measures at the radius and calcaneum. Outcomes were assessed at baseline, 12 months and 30 months using blinded operators. The analyses were performed on an intention-to-treat analysis. Mean femoral neck and trochanter BMD decreased in the control group [−1.1%, 95% confidence interval (CI) −0.1% to −2.1% and −1.6%, 95% CI −0.4% to −2.7%], while no change occurred in the exercise group. Mean trochanter BMC decreased more in the control group (−7.7%, 95% CI −9.7% to −5.6% vs. −2.9%, 95% CI −5.3 to −0.9). There were six falls that resulted in fractures in the exercise group and 16 in the control group during the 30-month intervention (P = 0.019). A significant bone loss occurred in both groups at the radius and calcaneum. In multivariate analysis, weight gain was associated with increased BMD and BMC at all femur sites both in the exercise group and in the pooled groups. In conclusion, impact exercise had no effect on BMD, while there was a positive effect on BMC at the trochanter. Exercise may prevent fall-related fractures in elderly women with low bone mass.

Keywords Elderly · Exercise · Osteoporosis · Population based · Randomized trial · Women

There was no conflict of interest.

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Introduction

Fractures due to skeletal fragility in elderly people are an increasing public health issue worldwide, and the already devastating medical and social costs can be expected to increase unless effective prevention and treatment regimens are developed. Hip fracture is the most severe complication of osteoporosis, placing the greatest demand on resources and having the greatest impact on patients because of increased mortality, long-term disability and loss of independence [1, 2].

Exercise has been shown to be essential for maximizing peak bone mass and reducing subsequent bone loss [3]. In premenopausal women, high-impact exercise has been suggested to be the most effective regimen, and it has been suggested that induced gain is maintained

after intervention [4]. A few meta-analyses [5, 6, 7, 8] have been published on the effectiveness of exercise on slowing postmenopausal bone loss. Evidence comes mainly from exercise intervention studies in postmenopausal women aged 65 or younger, and only two randomized controlled studies [9, 10] in women over 70 have been conducted. A recent Cochrane Review [8] revealed that evidence about the long-term effect of exercise on postmenopausal bone loss is inadequate, because the follow-up times have been short and the quality of the conducting of the interventions and the reporting of the outcomes has been poor. An overall conclusion from the meta-analyses is that after 1 year or longer, exercise may be effective for slowing bone loss from the lumbar spine and probably the neck of the femur and the wrist. The lack of reporting on the exercise characteristics (type, intensity, frequency, duration and mode) of the exercise interventions in postmenopausal women limits the conclusions that can be drawn about the effect of exercise.

The purpose of this first population-based partially blinded randomized controlled intervention study was to evaluate the effectiveness of a long-term impact training program on bone loss at the upper femur, calcaneum and distal radius in elderly women on an intention-to-treat basis.

Materials and methods

Study subjects

The name, address and social security number of the subjects were obtained from the National Population Register of Finland. In March 1997, a birth cohort of 1,690 elderly women was sent a questionnaire providing data on their lifetime medical and hormonal factors and physical activity. The women were invited to the first screening visit, and 1,222 women (72%) agreed to participate and underwent a measurement of bone mineral density (BMD) at the distal radius and assessment of calcaneum bone status (Fig. 1). The women were sequentially assigned an identification number. Ninety-six women were excluded because of medical reasons. Of the remaining 1,126 women, those who had a distal radius BMD value of more than 2 SD below the reference value ($n = 430$) were invited to the hip densitometry. Finally, those who had a hip BMD value of more than 2 SD below the reference value ($n = 160$) were included in the trial. The exclusion criteria for the exercise intervention were: use of a walking aid device other than a stick, bilateral hip joint replacement, unstable chronic illness, malignancy, medication known to affect bone

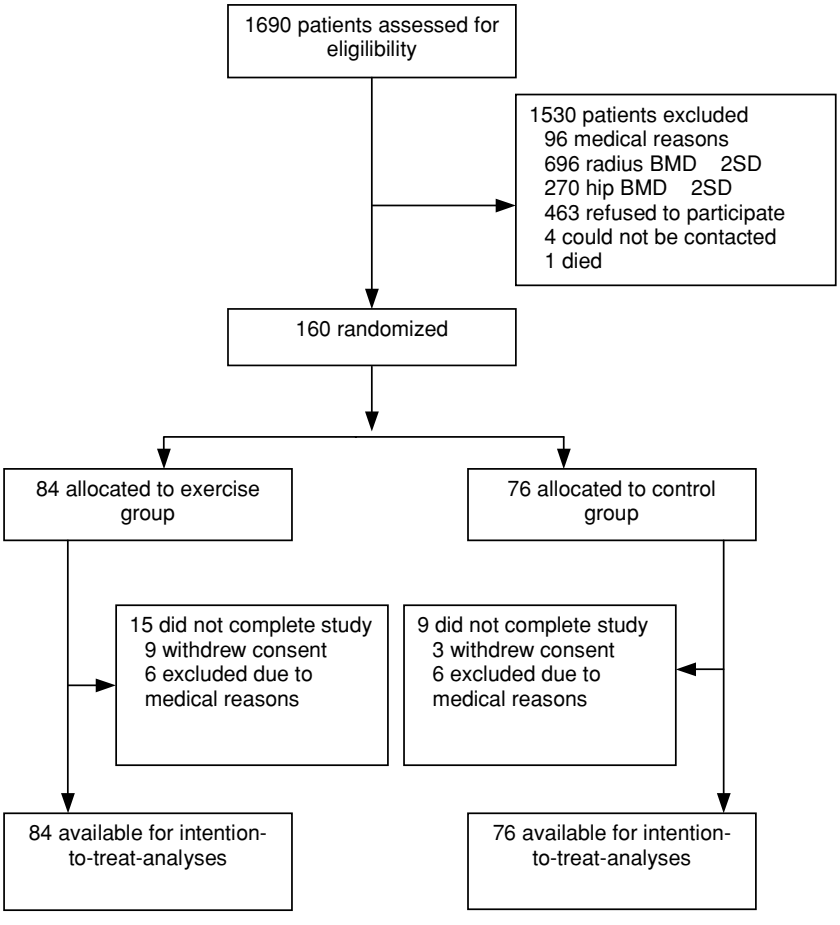

Fig. 1 Participant flow

density, severe cognitive impairment and involvement in other interventions. The women were randomly assigned to an exercise group ($n = 84$) and a control group ($n = 76$) using computer-generated random numbers. Each participant received sequentially, according to the original identification numbers, the next random assignment in the computer list. The randomization was performed after recruitment, and it was provided by a technical assistant not involved in the conduction of the trial. The assessors in direct contact with the participants during the study did not know to which group they had been allocated. The procedures of the study were in accordance with the Declaration of Helsinki, and formal ethics committee approval was obtained for the study. All 1,126 women who fulfilled the inclusion criteria and underwent the first screening test gave an informed and written consent.

Clinical examination and questionnaire

A clinical examination was performed by the same experienced nurse at baseline, 12 months and 30 months. The same questionnaire that was sent to the women before the first screening visit was administered by an interviewer to evaluate changes in medical condition, depressive symptoms [11], cognitive functions [12], activities of daily living with the self-report version of the Frenchay Activities Index [13], calcium intake, physical activity, consumption of alcohol and smoking. The details of the questionnaire have been published elsewhere [14]. Body weight and height were measured, and body mass index (BMI) was calculated as weight (kg) divided by height (m) squared. Percentage fat and lean mass were assessed with bioimpedance equipment (Bodystat 1500, Bodystat Ltd., Douglas, Isle of Man, UK). Basic mobility and dynamic balance were assessed with the Timed Up and Go (TUG) test [15]. Time spent on a 30-m walk [16] and the distance walked in 2 min [17] were measured. The participants were asked to classify themselves according to the frequency of exercise into one of the following five categories: (1) ''I do not strain myself more than is needed with light household tasks and daily activities;'' (2) ''I walk, cycle or exercise lightly in other ways at least once a week;'' (3) I engage in physical activity involving moderately heavy exertion (light sweating and breath-taking) at least two times per week;'' (4)''I engage in physical activity involving heavy exertion (moderate sweating and heavy breathing) at least two times per week.''

Bone measurements

Areal BMD and bone mineral content (BMC) measurements were performed at baseline, at 12 months and at 30 months at the left proximal femur by a dual-energy X-ray absorptiometry (DXA) (Dexa, Lunar Corporation, Madison, Wis.). The scanner was calibrated daily by bone phantoms (Hologic Corp., Bedford, Mass.). The coefficient of variation of the measurement in our laboratory is 0.5%. BMD of the dominant distal radius was measured at baseline and at 30 months by a peripheral DXA (Osteometer DTX 200, Osteometer Meditech, Roedovre, Denmark; precision range according to previous studies 1–2% [18]). Assessment of calcaneal broadband ultrasound attenuation (BUA, dB/MHz) and speed of sound (SOS, m/s) were performed by a quantitative ultrasound (QUS) (Sahara, Hologic, Bedford, Mass.; precision range 0.1–5% [18]) at baseline and at 30 months. Daily quality control on the Sahara QUS device was performed with external rubber phantom. The QUS device was not in clinical use during this study, but according to manufacturer's recommendation, the transducer pads were replaced each year. All the scannings and analyses with each item of equipment were performed by the same experienced operators unaware of the women's trial status.

Exercise program

The women in the exercise group were asked to attend hour-long training sessions, supervised by a qualified physiotherapist, for a 6-month period each year, from September 1998 until March 2001. Additionally, the participants were asked to train 20 min daily at home following a program that consisted of similar patterns of exercise to those in the supervised sessions. From April to September, the exercises only took place at home. Both the supervised and home exercise programs were updated on a bi-monthly basis to ensure progression and versatility. The supervised exercise sessions were undertaken as group activities. Approximately 45 min of each session was devoted to jumping and balance exercises, including walking, knee bends, leg lifts, heel rises and drops, dancing, stamping, stair climbing and stepping up and down from benches. Each session included a 15-min warm-up period. The exercises were performed on a moderately hard vinyl carpet, barefooted or using very light gymnastic shoes. The exercisers were advised to keep their knees locked during landing whenever painless and possible.

The intervention group kept a diary of their daily physical activity, and the supervising physiotherapist was responsible for monitoring their daily logs. When the women in the exercise group performed their supervised home exercise program, they marked a cross in their diary. Compliance with home exercises was checked by counting the crosses. Subjects assigned to the control group were asked to continue their daily routine activities. The participants of both groups were contacted every 3 months by telephone or by mail to record possible changes in their state of health or medication. The women were asked whether a fall had occurred, and, if so, about the time, place, estimated cause and consequences of the fall events and the need for medical treatment. In the event of a need for medical treatment,

the self-reported information was checked from the medical records. Falls and fractures occurring in connection with motor vehicle and bicycle accidents were not included. All the subjects in the experimental and control groups were invited to attend twice yearly seminars given by experts in the field. Topics included general information on nutrition, health, medical treatment and fall prevention.

Statistical analysis

We estimated that at the 5% level we would require 64 women in each group to give an 80% power to detect a 0.02 g/cm^2 difference in the primary outcome (femoral neck, trochanter and total hip BMD with an SD of 0.04 g/cm^2) between the groups. All the 160 subjects were included, allowing a 25% rate of attrition in the exercise group, and a 15% rate of attrition in the control group. The data were analyzed using SPSS 11.5 for Windows. The absolute and percentage changes from baseline were calculated for each bone characteristic. The means with 95% confidence intervals (CI) were calculated for change within a group and for difference between the groups. The paired samples *t* test was used to analyze the within group change from baseline, and the *t* test for independent samples was used to compare the treatment group with the control group. The analysis of variance for repeated measurements was performed to compare the change from baseline in femoral head BMD and BMC in the two study groups, and the three a priori set null hypotheses were: (1) there is no interaction between group and time; (2) there is no difference between the group main effects; (3) there is no difference between the time main effects. Multiple linear regression analysis using all variables associated with BMD and BMC in univariate analyses was performed to evaluate the determinants of bone response within the exercise group and the pooled groups. Data were analyzed on an intention to treat basis, and any missing follow up data was replaced with the last known value even if this was the baseline value.

Results

The mean age of the women for both groups was 73 years at the beginning of the intervention (Table 1). Sixty-eight women (81.0%) in the exercise group and 65 (85.5%) women in the control group completed the study. In both groups all but four of the withdrawals occurred during the 1st year of the intervention. Reasons for withdrawal were unwillingness to continue (n = 12), new or worsening health problems (n = 7) or medication included in the initial exclusion criteria (n = 5). The drop-out subjects were similar in respect to weight, height, femoral and radial BMD, calcaneal QUS values and calcium intake compared to those who continued to participate. Attendance at the exercise sessions averaged 78% during the first supervised 6-month period, 74% during the second supervised period and 73% during the last supervised 6 months. The average frequency of performing the home exercise program was three times per week. Three women in the exercise group experienced musculoskeletal problems that required minor modifications in the training regimen. All of these women completed the exercise program without further problems. Two women had to suspend training due to knee arthroplasty, six women due to neurological or cardiovascular problems and six women due to glaucoma surgery. They all returned to the exercise program and completed a modified regimen without problems.

Table 1 Baseline characteristics of subjects. Values are numbers (percentages) unless otherwise stated. *BMI* body mass index

Characteristic	Exercise group (n = 84)	Control group (n = 76)
Mean age (years) (SD)	72.9 (1.1)	72.8 (1.2)
Mean height (cm) (SD)	154.5 (4.9)	156.3 (5.4)
Mean weight (kg) (SD)	61.2 (7.9)	62.2 (9.2)
Mean BMI (kg/m^2)(SD)	25.7 (3.4)	25.5 (3.5)
Mean body fat (%) (SD)	40.7 (4.2)	39.4 (5.9)
Medical history		
Hypertension	22 (26.2)	21 (27.6)
Type II diabetes	4 (4.8)	6 (7.9)
Rheumatoid arthritis	5 (6.0)	4 (5.3)
Any neurological disease	4 (4.8)	4 (5.3)
Estrogen	3 (3.6)	1 (1.3)
Thiazide diuretics	9 (10.7)	11 (14.5)
Statins	4 (4.8)	6 (7.9)
Thyroid hormone	8 (9.5)	4 (5.3)
Lifestyle and nutritional factors		
Daily smoking	5 (6.0)	8 (10.5)
Weekly consumption of alcohol	4 (4.8)	6 (7.9)
Mean calcium intake (mg/day) (SD)	846 (387)	773 (299)
No regular physical exercise	7 (9.5)	8 (11.3)
History of any fracture beyond the age of 40	36 (42.9)	34 (48.6)
History of falls during the last 3 months	6 (7.1)	11 (14.5)

Bone mineral density and bone mineral content

Figures 2, 3 and 4 show the change in hip BMD and BMC over the study period in the exercise and control group and the significance of the difference in the repeated-measures ANOVA. None of the bone sites demonstrated significant BMD differences between exercise and control group at any evaluation sessions (12 and 30 months) and the interaction effects (time × group) for all bone density parameters were nonsignificant. The session effect in BMD for the neck and trochanteric region were significant within the control group [−1.1%; 95% CI, −2.1% to −0.1% (P = 0.04) for the neck and −1.6%; 95% CI, −2.7% to −0.4% (P = 0.01) for the trochanter], but no change occurred within the exercise group [−0.6%; 95% CI, −1.6% to

0.10% ($P = 0.07$) and −0.3%; 95% CI, −1.6% to 0.8% ($P = 0.48$)]. A significant decrease in BMC occurred at the trochanter within both groups over time (repeated measures ANOVA, $P = 0.001$), the loss of BMC being greater in the control group (−7.7%; 95% CI, −9.7% to −5.6% vs. −2.9%; 95% CI, −5.3% to −0.9%; repeated measures ANOVA, P for the interaction effect = 0.001). The absolute BMD and BMC values measured with DXA over the 30-month trial at various hip sites in the two groups are presented in the Table 2.

In the linear multiple regression analyses adjusted for attendance (%) at the training sessions, each kg increment in weight increased the total hip BMD by 0.5% ($r^2 = 30.2\%$, model $P < 0.001$) and the total hip BMC by 0.8% ($r^2 = 38.3\%$, model $P < 0.001$) within the exercise group. Also, within the pooled groups, weight change over time was the most significant determinant of bone loss at the hip, with each kg increment in weight accounting for a 0.5% increase in the total hip BMD ($r^2 = 22.2\%$, model $P < 0.001$) and 0.8% of the change in the total hip BMC ($r^2 = 29.8\%$, model $P < 0.001$).

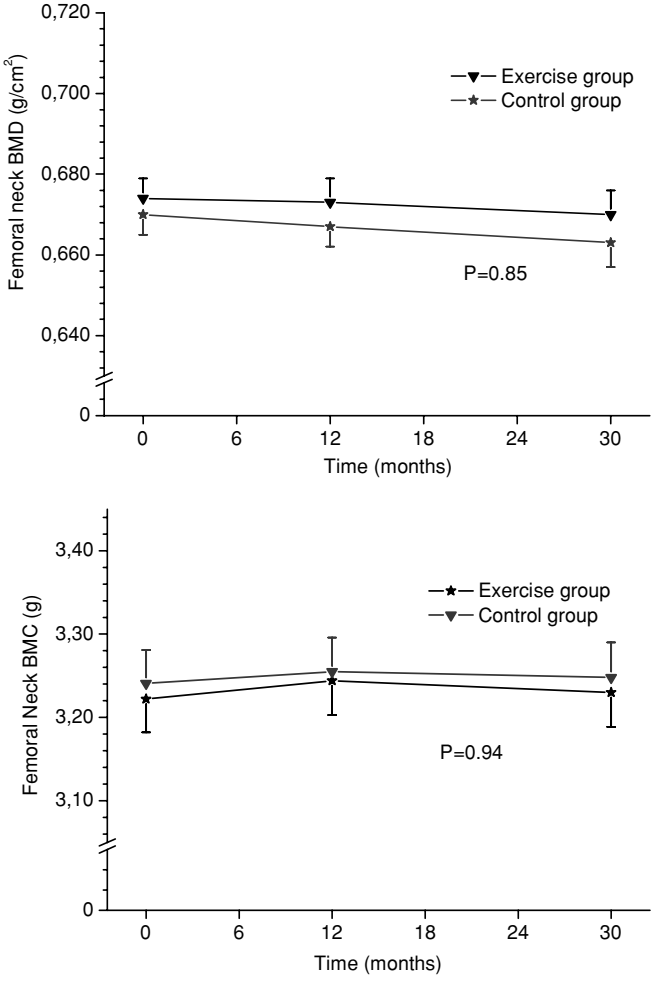

Fig. 2 Change from baseline in femoral neck bone mineral density (g/cm^2) and bone mineral content (g) during the study period and the significance of the difference between the groups in the repeated-measures Anova. *Bars* = SEM

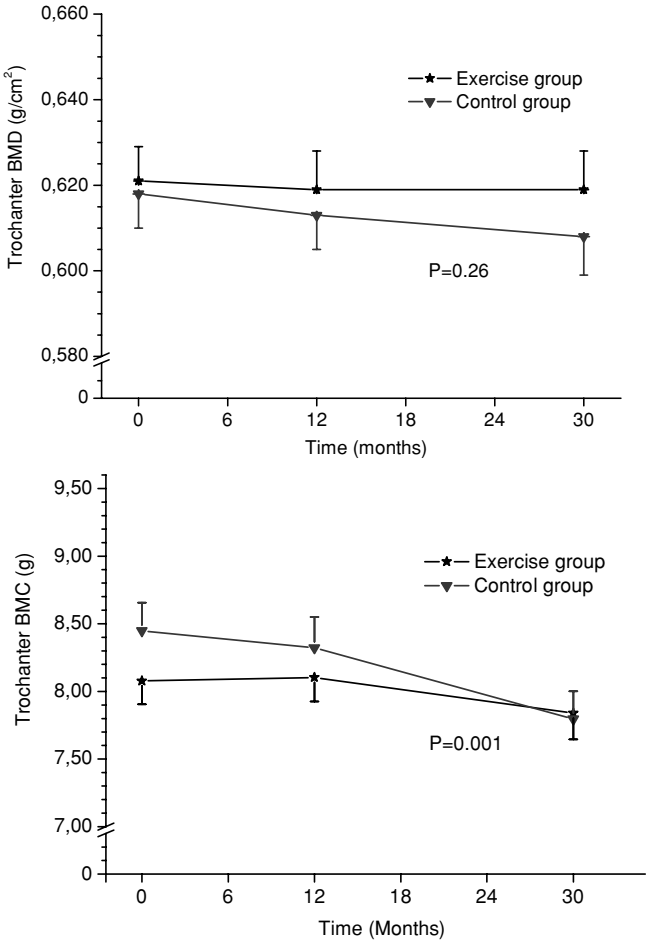

Fig. 3 Change from baseline in trochanter bone mineral density (g/cm^2) and bone mineral content (g) during the study period and the significance of the difference between the groups in the repeated-measures Anova. *Bars* = SEM

The decrement of the mean BMD at the distal and ultradistal radius was significant in the exercise group (−3.8%; $P = 0.001$ and −3.1%; $P = 0.003$) and the control group (−3.1%; $P = 0.001$ and −3.4%; $P = 0.01$), but the means of the two groups were not significantly different (Table 3). Nor did exercise have any significant effect on the rate of bone loss at the calcaneum, where the SOS and BUA values decreased significantly and similarly in both groups.

During the 30-month follow-up, there were 88 falls in the exercise group and 101 falls in the control group ($P = 0.10$). The incidence of fall-related fractures was higher in the control group ($n = 16$) than in the exercise group ($n = 6$; $P = 0.019$). One woman in the control group had two fractures, and all other 20 women had one fracture. The distribution of types of fractures between the exercise group and the control group was as follows: the exercise group (radius 4, fibula 1, clavicula 1) and control group (radius 3, finger 1, fibula 2, humerus 4, elbow 2, rib 1, vertebra 2, pelvis 1). All the subjects with fractures returned to the exercise program and completed a modified regimen without problems.

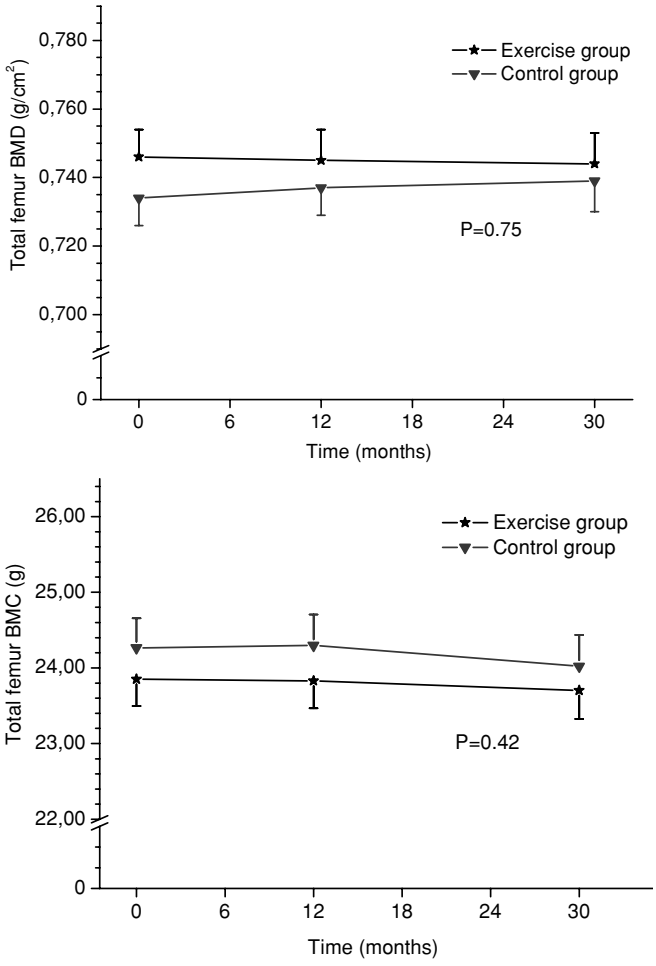

Fig. 4 Change from baseline in total proximal femur bone mineral density (g/cm^2) and bone mineral content (g) during the study period and the significance of the difference between the groups in the repeated-measures Anova. *Bars* = SEM

During the 30-month intervention, there was a mean weight gain of 0.8 kg (95% CI, −0.1 kg to 1.7 kg) in the exercise group and a mean weight gain of 1.1 kg (95% CI, 0.5 kg to 1.7 kg) in the control group (repeated measures ANOVA, $P = 0.46$). Also, the fat-% increased similarly in the exercise and control group (1.4%; 95% CI, 0.8% to 2.0% vs. 2.2%; 95% CI, 1.4% to 3.1%; repeated measures ANOVA, $P = 0.24$). Activities in daily living assessed with the Frenchay Activies Index showed a significant and similar decrease within the exercise group (−1.7; $P = 0.004$) and the control group (−2.8; $P < 0.001$; $P = 0.25$, repeated measures ANOVA). The proportion of subjects who reported a shift to a higher category of physical activity within the four categories from baseline to the end of the intervention was a little higher among the exercise group [11 (15.5%) vs. 7 (9.6%)], but the difference was not statistically significant. The women in the control group reported a shift to a lower category slightly more often than the women in the exercise group [17 (23.0%) vs. 9 (12.5%); $P = 0.10$). Calcium intake was not different among the groups before the intervention and decreased slightly and similarly in both groups over the 30 months of observation.

Discussion

This is the first population-based randomized controlled study to assess the effect of impact exercise on bone loss at different anatomical sites in elderly women who are considered to be at risk of osteoporotic fractures on the basis of a low baseline BMD. Thirty months of weight-bearing exercise proved to be safe and showed efficacy in slowing or stopping bone loss, especially at the trochanter, and the exercisers also had less fall-related fractures than the control group during the follow-up period. Furthermore, there was a relation between weight gain and increase in BMD and BMC at the hip.

Although recent systematic reviews [7, 8] clearly show that exercise slows the rate of bone loss at the spine in postmenopausal women, there is a great deal of heterogeneity between the study results for the proximal femur in elderly women [9, 10, 19, 20, 21]. Two years of brisk walking had a positive effect on femoral neck BMD (mean age of the women 67 years) [20], while 10 months of stepping (mean age 76 years) [9] and mixed balance- and weight-bearing exercise (mean age 72 years) [10] had a negative effect on proximal femur BMD. The osteogenic effects of exercise training are suggested to be site-specific to the anatomic sites at which the mechanical strains occur [22, 23]. This was further emphasized by a recent randomized trial, where 157 elderly osteoporotic and osteopenic women performed daily heel drop exercises monitored with a home-use force platform [24]. The authors hypothesized, based on Wolff's law, that most participants would likely experience local BMD losses at some hip bone sites, and local increases at others, and they developed a new statistical classification model based on individual site-specific BMD changes. Although the authors found no significant differences between the groups in overall BMD measurements, they found that the result of the impact loading was a local redistribution in BMD. In our study, the exercise regimen was chosen to induce stress and tension especially in the proximal femur and the gluteal and hip muscles inserting to the lateral part of the trochanter. The results concerning the observed BMC changes at the trochanter are consistent with the chosen regimen and indicate the site-specificity of the training effect.

The intervention showed no effect on BMD at any hip bone sites, and this may be partly explained by the DXA-based method. Although DXA measurement is currently the golden standard technique for osteoporosis diagnosis, it has limitations, i.e., artifacts because of degenerative disease or fat folds overlying the proximal femur, which may confound BMD results in a nounion manner, particularly for osteopenic, osteoporotic and elderly patients [25, 26]. Positive correlations between

Table 2 Mean (95% CI) bone mineral density (*BMD*) and content (*BMC*) at different proximal femur sites at baseline, 12 and 30 months and the mean difference (95% CI) between the groups

	Exercise group (n = 84)	Control group (n = 76)	Difference (95% CI)	P value[a]
Neck BMD (g/cm^2)				
0 months	0.674 (0.663 to 0.685)	0.670 (0.660 to 0.680)	0.004 (−0.010 to 0.020)	
12 months	0.673 (0.661 to 0.684)	0.667 (0.657 to 0.678)	0.006 (−0.010 to 0.021)	0.78
30 months	0.670 (0.657 to 0.681)	0.663 (0.651 to 0.674) [b]	0.007 (−0.010 to 0.024)	0.61
Neck BMC (g)				
0 months	3.222 (3.143 to 3.302	3.241 (3.161 to 3.322)	−0.019 (−0 132 to 0.093)	
12 months	3.244 (3.162 to 3.326)	3.255 (3.174 to 3.336)	−0.011 (−0.126 to 0.104)	0.73
30 months	3.230 (3.148 to 3.312)	3.248 (3.164 to 3.332)	−0.018 (−0.134 to 0.100)	0.95
Trochanter BMD (g/cm^2)				
0 months	0.621 (0.605 to 0.638)	0.618 (0.601 to 0.635)	0.003 (−0.020 to 0.026)	
12 months	0.619 (0.602 to 0.636)	0.613 (0.596 to 0.630) [b]	0.006 (−0.017 to 0.031)	0.30
30 months	0.619 (0.601 to 0.636)	0.608 (0.591 to 0.626) [b]	0.011 (−0.014 to 0.035)	0.17
Trochanter BMC (g)				
0 months	8.077 (7.736 to 8.418)	8.449 (8.037 to 8.862)	−0.372 (−0.900 to 0.155)	
12 months	8.104 (7.750 to 8.457)	8.323 (7.872 to 8.775)	−0.219 (−0.783 to 0.344)	0.10
30 months	7.839 (7.454 to 8.224) [c]	7.796 (7.388 to 8.205) [d]	0.043 (−0.514 to 0.600)	0.001
Total proximal femur BMD (g/cm^2)				
0 months	0.746 (0.730 to 0.762)	0.734 (0.718 to 0.751)	0.012 (−0.012 to 0.035)	
12 months	0.745 (0.728 to 0.762)	0.737 (0.721 to 0.754)	0.008 (−0.016 to 0.031)	0.44
30 months	0.744 (0.727 to 0.762)	0.740 (0.722 to 0.758)	0.004 (−0.021 to 0.030)	0.55
Total proximal femur BMC (g)				
0 months	23.850 (23.148 to 24.553)	24.266 (23.487 to 25.044)	−0.416 (−1.453 to 0.623)	
12 months	23.827 (23.112 to 24.542)	24.299 (23.489 to 25.108)	−0.472 (−1.534 to 0.596)	0.58
30 months	23.702 (22.954 to 24.450	24.034 (23.211 to 24.858)	−0.332 (−1.433 to 0.769)	0.45

[a]Difference between changes from baseline in exercise and control group, independent samples t -test. [b] $P < 0.05$; [c]$P < 0.01$; [d]$P < 0.001$ significance for within-group difference from baseline, paired samples t -test

soft tissue anthropometrics and BMD may also be confounded by these inaccuracies [26]. Moreover, degenerative changes at the hip joint may limit rotation of the hip joint, and interpretation of serial BMD values may be confounded by the changes in the positioning of the hip during DXA scanning [27]. Recently, it has been suggested that studying bending resistance and geometry along with conventional bone mass measurements could lead to a better understanding of the effect of physical activity on bone. A large population-based prospective study revealed that changes in hip loading are associated with mechanically appropriate alteration in the section modulus, an index of bending and torsional strength [28]. Kaptoge et al. found that hip section modulus was more strongly related to physical activity than BMD in elderly women [29]. It has also been suggested that the true material density of bone tissue remains quite constant with age [30], whereas the size, geometry and trabecular architecture of bones vary considerably between different sites and individuals, and like other bones, the

Table 3 Mean (95%CI) radial DXA values and calcaneal QUS values at baseline and at 30-month follow-up visit

	Exercise group (n = 84)	Control group (n = 76)	Difference (95% CI)	P value[a]
Radial DXA				
Distal BMD (g/cm^2)				
0 months	0.290 (0.281 to 0.299)	0.291 (0.281 to 0.300)	−0.001 (−0.014 to 0.012)	
30 months	0.279 (0.269 to 0.289) [d]	0.282 (0.272 to 0.292) [d]	−0.003 (−0.017 to 0.011)	0.44
Ultradistal BMD (g/cm^2)				
0 months	0.229 (0.220 to 0.237)	0.234 (0.224 to 0.244)	−0.005 (−0.018 to 0.008)	
30 months	0.222 (0.213 to 0.230) [c]	0.226 (0.217 to 0.236) [c]	−0.004 (−0.018 to 0.008)	0.94
Calcaneal QUS				
BUA (dB/MHz)				
0 months	52.78 (49.92 to 55.65)	53.05 (49.42 to 56.67)	−0.27 (−4.79 to 4.27)	
30 months	53.05 (50.15 to 55.95)	53.22 (49.57 to 56.87)	−0.17 (−4.74 to 4.40)	0.93
SOS (m/s)				
0 months	1,517.33 (1,512.44 to 1,522.22)	1,514.81 (1,509.19 to 1,520.43)	2.52 (−4.83 to 9.87)	
30 months	1,511.15 (1,506.37 to 1,515.94) [d]	1,508.30 (1,502.89 to 1,513.72) [d]	2.85 (−4.29 to 9.99)	0.84

[a]Difference between changes from baseline in exercise and control group, independent samples t -test. [b] $P < 0.05$; [c]$P < 0.01$; [d]$P < 0.001$ significance for within-group difference from baseline, paired samples t -test

femoral neck expands slowly with ageing [31]. In addition to BMD, we also reported the BMC value, which reflects the amount of mineral of the given bone site, and has been suggested as a measure of the cross-sectional area occupied by bone mineral. An increase in the projected bone area as a result of increased bone size, e.g., from sub-periosteal expansion, would lead to a decrease in BMD even if the BMC remains unchanged [32, 33]. BMC changes under unchanged BMD in this study may suggest for some changes in the bone area or bone geometry. However, BMC is not able to differentiate between the actual size, geometry, structure or composition of the given site [26], and therefore, no detailed conclusion can be made on the geometrical changes in the present study.

Osteoporosis only has clinical and public health importance because of the fractures that arise as a consequence of the condition. In our data there was no significant difference in the falling rate during the study period between the groups, but the women in the control group had fall-related fractures significantly more frequently than the women in the exercise group. The fracture was located most frequently in the radius. About 90% of all hip fractures result from a fall, but only about 1% of falls in elderly women result in a hip fracture, suggesting that the likelihood of fracture is affected by the circumstances and biomechanics of the fall. It has been suggested that high kinetic energies, the orientation of the faller, reduced soft tissue padding over the hip and inability of the faller to effectively use their arms to reduce the energy of the fall contribute to the occurrence of fracture [34]. The exercise regimen in our intervention was mainly aimed at stressing the skeleton, but it was also aimed to stress the balance system. Our data suggest that the chosen regimen might be effective in reducing falls and fractures, but the sample size was not large enough for these outcomes, and no definite conclusions can be drawn from this data.

Compared to previous studies on elderly women [7], the attendance and adherence rates were high in our study, despite the population-based approach. This suggests that the chosen regimen could have a high feasibility in the general population. Furthermore, the exercise regimen proved to be safe judging from the minimum need for medical services over the entire follow-up.

Calcaneum and distal radius were chosen for the measurement of bone density, because they both encompass a large volume of trabecular bone known to be affected by postmenopausal osteoporosis. The distal radius served as a reference bone, and it was anticipated that the intervention would have no effect on the radius and the possible changes in BMD would reflect the age-related changes in a non-weight-bearing bone. Both measurements are also reported to predict independently the occurrence of fractures [35, 36]. Although the calcaneum is known to be particularly sensitive to the amount of exercise the patient takes, the exercise had no effect on the bone values measured by QUS at the calcaneum. One explanation may be that the exercise did not induce enough gravitational forces (impacts) to strengthen the calcaneum, and the positive response at the trochanter may have been mainly a result of muscular pull through tendinous attachments at the trochanter. Secondly, quality assurance and quality control have been shown to be problematic, especially with QUS equipment [37]. Nevertheless, daily QC was performed according to the manufacturer's recommendations, and the transducer pads were replaced even more often than recommended. It is known, however, that these manufacturer-specific phantoms that are used with QUS devices are influenced by many external factors, and they cannot be regarded as good indicators of device stability. Thirdly, the elderly women in the exercise group found it difficult to perform the exercises stamping their feet, because they had always been thought to move femininely and prettily, keeping their back straight and ankle plantar-flexed while doing gymnastic exercises.

In this study, change in weight during the follow-up period was the main determinant of the variation in BMD and BMC of the hip, indicating that maintaining or even gaining weight seems to retard excessive bone loss at the hip in elderly women. This is in agreement with the previous studies suggesting that weight and weight increase are associated with maintenance of bone mass and reduced bone loss, whereas thinness and weight loss lead to enhanced bone loss [38, 39]. It is known that elderly women tend to lose weight rather than gain weight. In our study, the opposite finding may be explained by the general information on nutrition and health given to the participants. Although inaccuracies in the DXA method may confuse the interpretation of the association between soft tissue anthropometry and BMD, it should be kept in mind that low body weight and unintentional weight loss have also been reported to be manifestations of overall frailty, a syndrome that is predictive of incident falls, fractures, disability, hospitalization and mortality [40]. Maintenance of body weight should therefore be emphasized in health education and interventions targeted at elderly women.

This study has some limitations. There are many possible sources of error in repeat bone density tests. In addition to the before-mentioned inaccuracies in DXA-based methods, variations from year to year in the machine readings, technologists and positioning will decrease the reproducibility. These errors cause the phenomenon of regression to the mean; women who apparently lose bone during the 1st year of a trial will then apparently gain it back over the 2nd year. We tried to overcome this by careful operator training. Furthermore, the bone density printouts were examined to see if there were noticeable differences in the position or the area measured. In this study, dietary calcium intake during four time periods of lifespan and during the intervention was computed as the sum of intakes of milk and cheese. A more accurate method would have been a food frequency questionnaire or a food record. Nelson

et al. [41] have shown that at least 8 days of diet records are needed to achieve a reliability coefficient for calcium intake of over 0.9. Furthermore, the way we handled missing outcome data may have introduced some bias. Our aim in this study was pragmatic, however, and the purpose was to answer "the public health question" by ignoring adherence when the data were analyzed. On treatment analyzes would have overestimated the exercise effects and not reflected the way exercise would perform in the population. During the study, we tried to minimize missing information and could follow up many of the women who had withdrawn from the intervention. We also acknowledge that improving bone mass does not guarantee fewer fractures. Although there were fewer factures in the exercise group during the follow-up, the sample size of this study was not large enough for this outcome, and no conclusions can be drawn from this data. Future research using falls and fractures as the primary outcome measures are needed to confirm the role of this kind of exercise training in fracture prevention in those women with low bone mass.

Evidence about the long-term effect of exercise on postmenopausal bone loss has been inadequate mainly due to the short follow-up periods and selected early postmenopausal study populations. This population-based randomized controlled 30-month trial provides evidence that a mainly home-based impact exercise program has no effect on BMD at the hip, but there may a positive effect on BMC at the trochanter. Exercise may prevent fall-related fractures in elderly women with low bone mass. Long-term follow-up will provide evidence as to whether or not these gains are maintained.

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