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ORIGINAL ARTICLE

# Effects of high-impact exercise on bone mineral density: a randomized controlled trial in premenopausal women

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**Abstract** Introduction: The purpose of this randomized controlled study was to assess the effects of high-impact exercise on the bone mineral density (BMD) of premenopausal women at the population level. Materials and methods: The study population consisted of a random population-based sample of 120 women from a cohort of 5,161 women, aged 35 to 40 years. They were randomly assigned to either an exercise or control group. The exercise regimen consisted of supervised, progressive high-impact exercises three times per week and an additional home program for 12 months. BMD was measured on the lumbar spine (L1–L4), proximal femur, and distal forearm, by dual-energy X-ray absorptiometry at baseline and after 12 months. Calcaneal bone was measured using quantitative ultrasound. Results: Thirty-nine women (65%) in the exercise group and 41 women (68%) in the control group completed the study. The exercise group demonstrated significant change compared with the control group in femoral neck BMD (1.1% vs −0.4%; $p=0.003$), intertrochanteric BMD (0.8% vs −0.2%; $p=0.029$), and total femoral BMD (0.1% vs −0.3%; $p=0.006$). No exercise-induced effects were found in the total lumbar BMD or in the lumbar vertebrae L2–L4. Instead, L1 BMD (2.2% vs −0.4%; $p=0.002$) increased significantly more in the exercise group than in the control group. Calcaneal broadband ultrasound attenuation showed also a significant change in the exercise group compared with the control group (7.3% vs −0.6%; $p=0.015$). The changes were also significant within the exercise group, but not within the control group. There were no significant differences between or within the groups in the distal forearm. Conclusions: This study indicates that high-impact exercise is effective in improving bone mineral density in the lumbar spine and upper femur in premenopausal women, and the results of the study may be generalized at the population level. This type of training may be an efficient, safe, and inexpensive way to prevent osteoporosis later in life.

**Keywords** Clinical trial · Mechanical loading · Osteoporosis · Population based · Premenopausal women · Prevention

## Introduction

Osteoporosis and osteoporotic fractures have become one of the major health problems in Western countries [1]. One in three white women over the age of 50 will experience at least one fragility fracture during their remaining life [2]. The 1st-year total direct cost of osteoporotic fractures is estimated to be 25 billion euros in Europe [3]. There is therefore an urgent need to develop preventive strategies.

Epidemiological, clinical, and experimental exercise studies have suggested that exercise enhances bone development and augments bone mineral density (BMD) during adolescence and may prevent osteoporosis and fractures during old age [4, 5, 6, 7, 8]. Regular exercise, especially resistance and high-impact activities, contributes to development of high peak bone mass and may reduce risk of falls and osteoporotic fractures in later life [9, 10]. A recent meta-analysis indicated that high-impact exercise was most effective regarding the femoral neck BMD [9], and it has also been suggested that gains induced by high-impact exercise are maintained after intervention [11].

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There are few randomized controlled prospective studies concerning exercise and bone mineral density in premenopausal women [12, 13, 14, 15, 16], and most of the studies have included voluntary premenopausal women who are likely to be willing to participate in health-related physical activities [17]. Additionally, study samples in exercise interventions may have been selected and limited [9]. To our knowledge, no population-based randomized controlled exercise trials in premenopausal women have been conducted. Therefore, our aim was to evaluate the effects of high-impact physical exercise on lumbar, hip, and distal forearm BMD and calcaneal ultrasound attenuation in a population-based randomized cohort of premenopausal women.

## Materials and methods

### Subjects

The study population consisted of a random sample of Finnish women from a cohort of 5,161 women aged 35 to 40 years residing in the city of Oulu, Finland, in March 2002 (Fig. 1). The name, address, and social security number of the subjects were obtained from the National Population Register of Finland. To detect a 3% (or more) difference between the exercise and control groups in BMD, with 5% significance level and power of 80%, 120 participants were needed with an equal dropout rate of ten subjects per group. The participants were contacted in random order, and to get 120 participants, 287 women were contacted. Of these, 125 women were unwilling to participate, and 42 women were excluded. The exclusion criteria were cardiovascular, musculoskeletal, respiratory, or other chronic diseases that might limit training and testing; diseases or medication affecting the bone; pregnancy and breast-feeding; and regular current or previous participation in impact-type exercises and long-distance running more than three times a week. The subjects were randomly assigned to an exercise group ($n = 60$) or a nonexercise control group ($n = 60$) using a computer-generated number code. The study protocol was approved by the Ethical Committee of the Northern Ostrobothnia Hospital District, and all the participants gave informed and written consent. The procedure of the study was in accordance with the Declaration of Helsinki.

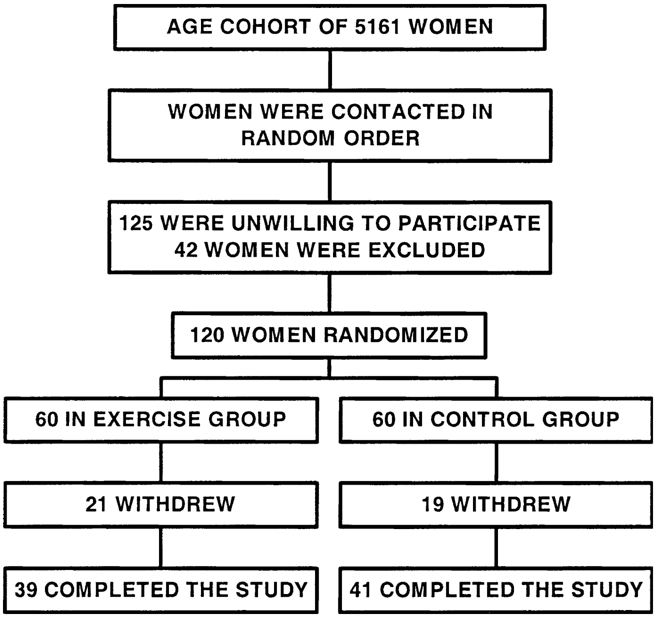

**Fig. 1** Study protocol

### Questionnaires and anthropometry

A self-administered health questionnaire was mailed to all contacted women, requesting information regarding weight history and height, occupational history [18], current and past physical activity [19] and medical factors, fractures beyond the age of 15, menarcheal age, menstrual status, parity, months of breast-feeding, current and previous use of hormones, current and previous dietary factors including intake of calcium and vitamin D [20], current and past smoking and consumption of alcohol, and possible vitamin or mineral supplementation.

Anthropometrical characteristics were measured at baseline and after 12 months. Body weight and height were measured, and body mass index was calculated. Body fat and lean mass percentages were measured with bioimpedance equipment (Bodystat 1500; Bodystat, Douglas, Isle of Man, UK).

### Bone measurements

Areal bone mineral density (BMD, g/cm$^2$) was measured on the lumbar spine (L1–L4) and the left proximal femur with dual-energy X-ray absorptiometry (DXA) (Hologic Delphi QDR; Hologic, Bedford, MA, USA). The femoral neck, trochanter, intertrochanter, and Ward's triangle of the hip, and vertebras L1–L4 were analyzed separately. The same operator did all of the scanning and analyses. The scanner was calibrated daily by bone phantoms (Hologic, Bedford, MA, USA) for quality assurance, and no evidence of machine drift appeared during this study. BMD was also measured from the distal ulna, distal radius, and ultradistal radius, with peripheral DXA (Osteometer DTX 200; Osteometer Meditech, Roedovre, Denmark). Calcaneal broadband ultrasound attenuation (BUA, dB/MHz) and speed of sound (SOS, m/s) were measured using quantitative ultrasound (QUS) (Hologic Sahara; Hologic, Bedford, MA, USA). The measurements were performed in the beginning and at the end of the intervention.

### Exercise training protocol

The training sessions were carried out three times a week for 12 months. All training sessions were supervised by a physiotherapist and were done with the accompaniment of music. The training regimen was based upon a pilot study and upon the previous literature. Each workout lasted 60 min, including a 10-min warm-up, a 40-min high-impact training session, and a 10-min cooling-down and stretching period. The warm-up period included walking and running on the spot, with and without arm movements and knee bends. The high-impact period included step patterns, stamping, jumping, running, and walking. After 3 months of training, a one-step bench (height 10 cm) (Reebok UK, Lancaster, UK) was used to enhance the impact effect and after 6 months, two or three benches were used. The cool-down mainly consisted of stretching. The programs were modified bimonthly and during the intervention, the program became more demanding and included higher jumps and drops. Additionally, the participants were asked to train 10 min daily at home following a specially designed program, which consisted of similar patterns of exercise to those in the supervised sessions. The home program was also modified seasonally. The women in the control group were asked to continue their normal daily life and to maintain their current physical activity during the 12 months. All participants carried a physical activity recorder (Newtest, Oulu, Finland) on their waist during the study. These physical activity data will be analyzed and reported later.

### Statistical analysis

The data were analyzed using the SPSS statistical package (SPPS 11.5 for Windows; SPPS, Chicago, IL, USA). The results are reported as mean and standard deviation (SD) or 95% confidence interval (95% CI). All participants, including the subjects who discontinued exercise, were invited for the follow-up measurements. All subjects with both baseline and follow-up data were included in the analysis according to their group assignment. Distributions of outcome variables were tested for normality. Independent samples *t*-test and $\chi$-square tests were used to assess the differences between the study subjects and women who did not participate in the study. Independent samples *t*-test (or Mann-Whitney *U*-test if the distribution was not normal) was used to compare the groups with respect to changes from baseline in bone mineral density and also the differences between the study subjects and dropouts. Paired samples *t*-test (or Wilcoxon signed-rank test) was used to analyze the percentage change from baseline within the groups. Repeated measures analysis of covariance, using change of weight and BMI as covariates, was also performed, but analyses did not differ from unadjusted tests and are not reported. Analyses conducted on raw units of change and percentages produced similar results. In all tests, $p < 0.05$ was considered statistically significant.

## Results

### Characteristics and compliance

All 120 (100%) subjects and 70 (42%) excluded or unwilling women returned the baseline questionnaire. We analyzed the characteristics of the nonparticipants and found they did not differ from the study group (Table 1). The baseline characteristics of the participants are given in Table 2. Thirty-nine women (65%) in the training group and 41 women (68%) in the control group completed the study, representing a dropout frequency of 33.3%. There were no significant differences in any baseline variables between the dropouts and subjects who completed the study. The reasons for withdrawal were medical problems unrelated to the intervention program ($n = 3$), pregnancy ($n = 8$), moving from the study area ($n = 2$), change of vocation or schedule ($n = 6$), or other reasons ($n = 21$). The reasons for withdrawal were divided equally for both groups. For women completing the study, the average compliance defined as exercise sessions attended was 0.9 times

**Table 1** Characteristics of selected variables from baseline questionnaire. *NS* statistically not significant

| Characteristics | Control group ($n = 60$) | Exercise group ($n = 60$) | Nonparticipants ($n = 70$) | *p* Value[a] |
|---|---|---|---|---|
| Mean (SD) of continuous variables | | | | |
| Age, years | 38.5 (1.6) | 38.1 (1.7) | 37.8 (1.8) | NS |
| Height (as given by the subject), cm | 160.8 (20.1) | 164.5 (5.4) | 163.6 (18.7) | NS |
| Weight (as given by the subject, at the age of 30), kg | 63.0 (14.6) | 61.4 (8.8) | 62.1(8.3) | NS |
| Calcium intake, mg/day | 1,099 (511) | 1,099 (657) | 1,126 (451.1) | NS |
| Menarcheal age, years | 12.6 (1.5) | 12.8 (1.4) | 12.9 (1.1) | NS |
| Exercise, times/week | 3.8 (4.1) | 3.2 (2.6) | 3.5 (2.0) | NS |
| Exercise time (one period), min | 52.6 (21.7) | 49.4 (21.7) | 49.6 (20.5) | NS |
| Distribution of category variables, % | | | | |
| Smokers | 18.6 | 18.6 | 20.0 | NS |
| Alcohol > 1 drink/week | 26.7 | 22.0 | 24.3 | NS |
| Moderate exercise < 1 time/week (15 min) | 25.4 | 18.6 | 18.8 | NS |
| Heavy exercise < 1 time/week (15 min) | 45.8 | 49.2 | 37.1 | NS |
| Any fracture beyond the age of 15 years | 15.0 | 15.3 | 18.6 | NS |
| Any use of hormone medication (> 1 year) | 63.8 | 72.9 | 84.3 | NS |

[a] *p* Values for differences between groups

**Table 2** Baseline characteristics. Values are mean (SD)

| Characteristics | Control group ($n=60$) | Exercise group ($n=60$) |
|---|---|---|
| Age, years | 38.5 (1.6) | 38.1 (1.7) |
| Height, cm | 164.6 (6.0) | 162.8 (5.8) |
| Weight, kg | 69.4 (12.3) | 68.0 (12.6) |
| BMI | 25.7 (4.6) | 25.6 (4.4) |
| Percentage body fat | 31.2 (6.7) | 30.3 (6.4) |
| Fat mass, kg | 21.7 (8.4) | 20.8 (8.1) |
| Percentage lean body mass | 68.8 (6.7) | 69.7 (6.4) |
| Lean body mass, kg | 45.8 (4.7) | 46.0 (5.6) |
| Waist, cm | 82.3 (11.6) | 81.1 (10.3) |
| Hip, cm | 100.8 (8.0) | 100.5 (8.6) |
| Calcium intake, mg/day | 1,099 (511) | 1,099 (657) |

per week in supervised sessions and 2.2 in home sessions. The training program was well tolerated by all participants, and none developed stress-related or other injuries. During the study, the participants consulted an attending physician three times for the following reasons; mild ankle distorsion (one), tibial contusion (one), and unspecified stomach pain (one). The training was interrupted for at most 1 week because of these injuries. According to the endpoint questionnaires, 6 participants from the control group estimated that they were physically less active, 7 were more active, and 28 equally active compared with baseline.

### Anthropometrics and bone measurements

During the 12 months of high-impact exercise intervention, the training group lost some weight (−1.1%), while the control group had a minor weight gain (1.1%) ($p=0.082$). Bone mineral acquisition was significantly greater in the exercise group than in the control group at most of the lower extremity bone sites (Table 3). The exercise group demonstrated a significant gain compared with the control group in femoral neck BMD (1.1% vs −0.4%; $p=0.003$), intertrochanteric BMD (0.8% vs −0.2%; $p=0.029$), and total femoral BMD (0.1% vs −0.3%; $p=0.006$) (Fig. 2A). In addition, trochanteric BMD increased more in the exercise group than in the control group (1.1% vs 0.1%), the difference being almost statistically significant ($p=0.052$). The changes within the exercise group were significant in every variable in the upper femur. In the lumbar area, L1 BMD increased more in the exercise group than in the control group (2.2% vs −0.4%; $p=0.002$) and change was also significant within the exercise group (Fig. 2B). There were no significant changes in the L2–L4 region between or within the groups. Calcaneal BUA increased in the exercise group (7.3%) and decreased in the control group (−0.6%) ($p=0.015$). The changes between or within the groups were not significant in the non-weight-bearing sites in the distal forearm. Results from covariance analyses did not differ from unadjusted values.

## Discussion

The aim of this study was to investigate the effects of high-impact exercise on bone mineral density in premenopausal women. The study revealed that 12 months of regular high-impact exercise led to significantly increased bone mass at the loaded bone sites in lower extremities, but not at the non-weight-bearing bone sites. Our findings confirm the previous information on the positive effects of high-impact exercise on weight-bearing bones.

**Table 3** Bone measurements at baseline and at 12 months for completed subjects. Values are mean (SD). *NS* statistically not significant, *BMD* bone mineral density, *SOS* speed of sound, *BUA* broadband ultrasound attenuation

| | Control group ($n=41$) | | Exercise group ($n=39$) | | $p$ Value[a] |
|---|---|---|---|---|---|
| | Baseline | At 12 months | Baseline | At 12 months | |
| Femoral neck BMD, g/cm$^2$ | 0.804 (0.100) | 0.801 (0.099) | 0.789 (0.097) | 0.797 (0.093)$^{**}$ | 0.003 |
| Trochanter BMD, g/cm$^2$ | 0.701 (0.080) | 0.702 (0.078) | 0.698 (0.092) | 0.705 (0.093)$^{**}$ | 0.052 |
| Intertrochanter BMD, g/cm$^2$ | 1.141 (0.114) | 1.138 (0.114) | 1.128 (0.129) | 1.136 (0.132)$^{*}$ | 0.029 |
| Femoral total BMD, g/cm$^2$ | 0.950 (0.097) | 0.947 (0.096) | 0.940 (0.107) | 0.939 (0.115)$^{*\#}$ | 0.006$^{\#}$ |
| Ward's triangle BMD, g/cm$^2$ | 0.702 (0.107) | 0.708 (0.102) | 0.687 (0.104) | 0.705 (0.107)$^{***}$ | NS |
| L1 BMD, g/cm$^2$ | 0.931 (0.112) | 0.926 (0.112) | 0.916 (0.116) | 0.936 (0.115)$^{***}$ | 0.002 |
| L2 BMD, g/cm$^2$ | 1.028 (0.112) | 1.031 (0.104) | 1.028 (0.116) | 1.026 (0.116) | NS |
| L3 BMD, g/cm$^2$ | 1.062 (0.116) | 1.060 (0.108) | 1.050 (0.104) | 1.046 (0.106) | NS |
| L4 BMD, g/cm$^2$ | 1.067 (0.120) | 1.063 (0.119) | 1.040 0.110) | 1.036 (0.115) | NS |
| Lumbar total BMD, g/cm$^2$ | 1.027 (0.109) | 1.025 (0.104) | 1.014 (0.100) | 1.015 (0.102) | NS |
| Radius BMD, g/cm$^2$ | 0.488 (0.053) | 0.484 (0.055) | 0.503 (0.062) | 0.500 (0.059) | NS |
| Ulna BMD, g/cm$^2$ | 0.389 (0.051) | 0.397 (0.057) | 0.411 (0.059) | 0.408 (0.057) | NS$^{\#}$ |
| Distal radius BMD, g/cm$^2$ | 0.448 (0.050) | 0.448 (0.051) | 0.466 (0.059) | 0.464 (0.056) | NS |
| Ultradistal radius BMD, g/cm$^2$ | 0.351 (0.048) | 0.351 (0.050) | 0.368 (0.060) | 0.367 (0.057) | NS |
| Calcaneal SOS, m/s | 1,566.13 (25.04) | 1,570.19 (25.56) | 1,570.13 (29.11) | 1,574.38 (32.85) | NS |
| Calcaneal BUA, dB/MHz | 86.74 (14.75) | 85.98 (16.43) | 83.68 (13.74) | 89.76 (19.50) | 0.015 |

$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$, annual change within the group; $^{\#}$nonparametric test

[a] $p$ Values for differences between the control group and the exercise group over the 12-month study period

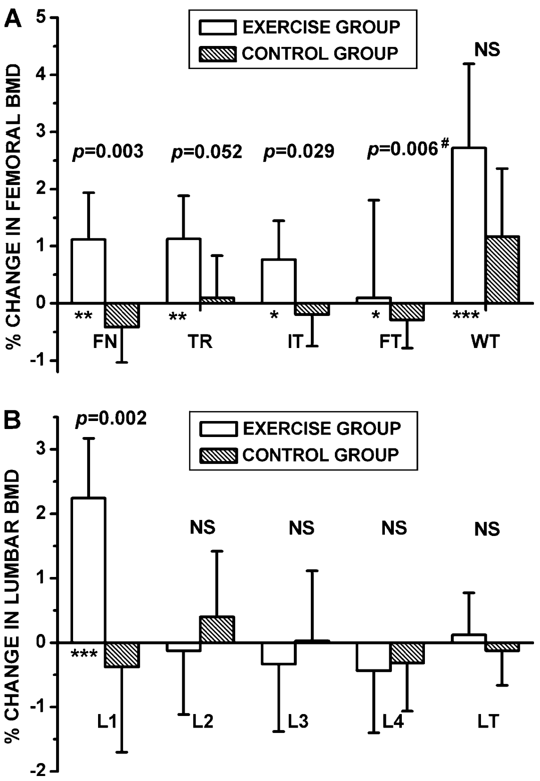

**Fig. 2A, B** Mean percentage changes in (**A**) femoral BMD and (**B**) lumbar BMD over the 12-month study period. The *error bars* represent 95% confidence intervals; *p* values are for differences between the groups over the study period. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$, for the change within the group; $^{\#}$nonparametric test. *LT* lumbar total, *FN* femoral neck, *TR* trochanter, *IT* intertrochanter, *FT* femoral total, and *WT* Ward's triangle

The training regimen proved to be safe, judging from the minimum need for medical services (3 visits over the entire study period) and also showed efficacy in improving the BMD in the upper femur with the mean attendance of 0.9 times per week in supervised sessions and 2.2 times per week in additional home sessions. Although the compliance with supervised sessions was moderately low, exercise-induced benefits appeared. This might point to the fact that even 1 to 2 hours of high-impact exercise plus two home-based exercise sessions would be enough to get benefits.

In our study, the exercise group demonstrated a significant 1.1% gain in femoral neck BMD and 7.3% in calcaneal BUA during the 12 months of high-impact exercise regimen, while there were no significant changes in control group values and no changes at the non-weight-bearing sites. In addition, BMD in the first lumbar vertebra increased 2.2%, but there were no exercise-induced effects in other vertebrae. Our findings are in agreement with previous randomized controlled high-impact exercise interventions in premenopausal women. In the study by Friedlander et al. [15], there were significant positive differences in BMD between the exercise and stretching groups for spinal trabecular (2.5%), femoral neck (2.4%), femoral trochanteric (2.3%), and calcaneal (6.4%) measurements after a 2-year high-impact exercise period. Heinonen et al. [16] observed a positive exercise effect on several risk factors for osteoporotic fractures, including a positive exercise effect on femoral neck BMD and lumbar spine BMD after 18 months of high-impact exercise training. Also Bassey et al. [21] reported significant differences between the exercise and control group in trochanter area BMD in premenopausal women after 5 months of training consisting of 50 vertical jumps on 6 days per week. Exercise regimen was effective on premenopausal women, but no significant differences were found in the bone mineral densities of postmenopausal women. Resistance and endurance training have also been reported to affect positively bone mineral status in premenopausal women [12, 14, 22]. Sinaki and colleagues [23] reported in their 3-year randomized controlled trial of dose-specific loading and strengthening exercises that lumbar spine BMD improved at 1 year with increased levels of exercise in the subjects who had lower BMD initially. However, at the completion of the study at 3 years, there was no significant change in BMD at the spine, hip, or midradius. Gleeson et al. [24] and Rockwell et al. [25] found that exercise training, including mostly weight-lifting, had no effect on bone mineral at the proximal femur. The apparently conflicting results may be due to differences in the type, intensity, frequency, or duration of exercise. In addition, the selection of the study samples and characteristics of the volunteers participating (e.g., age, nutrition, and hormonal status) may have affected the results. Indeed, recent meta-analyses have revealed clear positive effects of exercise training on lumbar spine and femoral neck in premenopausal women. The exercise training programs prevented or reversed almost 1% bone loss in premenopausal women [6, 9]. Furthermore, results of Wallace and Cumming [9] indicate also that both high-impact and non-impact exercises have a positive effect on the lumbar spine, but only high-impact exercise has a positive effect on the femoral neck. Moreover, aerobic and step exercises are popular among premenopausal women, a point which suggests high feasibility in the general population. In addition, risks of injuries are minor in healthy premenopausal women, so high-impact exercise seems to be suitable for the prevention of osteoporosis.

In the lumbar spine, no exercise-induced effects were found in the total lumbar BMD or in the lumbar vertebrae L2 to L4. Instead, impact exercise seemed to strengthen the lumbar vertebra L1. There is little existing data on the difference in the sensitivity of the lumbar vertebrae for impact loading, since most studies report only the combined BMD values for L1–L4 or L2–L4. The BMD measurement of the vertebrae one by one is less reliable than the combined values from a set of vertebrae, which has to be considered. However, the biomechanical loading varies between the vertebrae, which might partly explain the difference. The cross-sectional area of L1 is smaller than that of L2–L4, which generates higher loading stresses. At baseline, BMD was also lower in L1 than in the lower spine; impact-loading may therefore have had a more positive effect on this site with lower BMD [26]. Impact exercise may also have effects not only through weight-bearing, but the muscle forces may also play some role. It is known that the transversus abdominis muscle has an important role in spinal stiffness generation [27]. It supports the spine by intra-abdominal pressure [28], which may partly explain the differences between the vertebrae. The effects of impact-loading especially for the L1 may have great clinical importance since the number of atraumatic fractures is the greatest in L1 due to its role as the transition area (Th11–L1) between it and the low-mobility thoracic region, and hence the highly mobile lumbar area is susceptible to injury [29, 30, 31, 32]. These findings needs confirmation, however, and further studies are needed to clarify the effects of impact-loading on other vertebrae in the transition area.

In this study, the decrease in body weight in the exercise group and increase in the control group, although non-significant, may account for the responses of bone mineral status during the study period, so the results may underestimate the effects of exercise on bone. Body weight and weight changes are strongly linked to BMD changes in women regardless of body site. Weight and weight increase are associated with maintenance of BMD and reduced bone loss, whereas thinness and weight loss lead to low BMD and enhanced bone loss [33, 34, 35].

Our study had some limitations. The dropout rate of 33% over the 12-month period for this study was moderately high and higher than the expected 10 per group (17%) used in our power calculation. The high dropout rate is not unusual for exercise intervention trials. Studies by Snow-Harter et al. [12], Gleeson et al. [24], and Friedlander et al. [15] reported attrition rates of 40% in just 8 months, 38% in 1 year, and 50% in 2 years, respectively. Our population-based approach may have had an effect on the dropout rate. In most of the previous studies, voluntary premenopausal women already interested in exercise training have been recruited. The subjects may have been more active and interested in participating in the exercise program than the general population. In addition, the previous physical activity of the subjects in these studies may have been higher than in the general population. In this study, we recruited subjects from the whole age cohort residing in a specified area. Furthermore, we excluded the women already involved in high-impact exercise, thus we certainly also excluded the highly motivated subjects. However, the high number of women who were unwilling to participate in the study may have caused some selection bias. The dropout rate similar to other studies may indicate that the subjects in our study were not less motivated than the women in other studies, which were based on different recruitment. Premenopausal women seem to be more difficult to keep involved in a routine exercise program due to their numerous family responsibilities and career obligations compared with postmenopausal women. The reasons listed by our subjects for discontinued participation were predominantly unrelated to the study intervention and therefore unlikely to have affected the study outcomes.

In conclusion, this study indicates that high-impact exercise is safe and effective in improving bone mineral density in the lumbar spine and upper femur in healthy premenopausal women. If done on a regular basis, this type of training may be an efficient, safe, and inexpensive way of preventing osteoporosis later in life.

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