Calcif Tissue Int (2008) 82:171–181
DOI 10.1007/s00223-008-9105-x

CLINICAL INVESTIGATIONS

Influence of Calcium Intake and Physical Activity on Proximal Femur Bone Mass and Structure Among Pre- and Postmenopausal Women. A 10-Year Prospective Study

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Received: 7 November 2007 / Accepted: 2 January 2008 / Published online: 13 February 2008
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Abstract This 10-year follow-up evaluated the effect of physical activity and calcium intake on proximal femur bone mass (BMC) and structural indices (CSA and Z) and physical performance. A cohort of 133 premenopausal and 134 postmenopausal women with contrasting levels of physical activity (high [PA^+]) and low [PA^-]) and calcium intake (high [Ca^+] and low [Ca^-]) was measured with DXA at baseline and 5 and 10 years thereafter. Among premenopausal women, the mean (95% CI) femoral neck BMC was 3.8% (−0.1 to 7.8%) and the trochanter BMC 6.7% (2.4 to 11.3%) greater in the PA^+ group than the PA^- group. There was no difference between the Ca-intake groups. Among postmenopausal women, the mean femoral neck BMC was 4.2% (−0.2 to 8.8%) greater in the Ca^+ group than in the Ca^- group and 6.9% (2.2 to11.8%) greater in the PA^+ group than in the PA^- group. For trochanter BMC, the corresponding differences were 2.7% (−1.6 to 7.2%) and 5.5% (0.9 to 10.3%). The mean differences in CSA and Z were 3.8% (−0.9 to 8.7%) and 4.4% (−2.1 to 11.4%) in favor of the Ca^+ group and 6.8% (1.9 to 12.0%) and 9.6% (2.5 to 17.1%) in favor of the PA^+ group, respectively. Proximal femur BMC declined generally, but the initial differences between the physical activity and the calcium intake groups were maintained. High calcium intake seemed to slow the decline in trochanter BMC in premenopausal women, while high physical activity was beneficial for proximal femur, particularly among older women.

Keywords Bone mass · Bone strength · Calcium intake · Osteoporosis · Physical activity

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Fragility fractures are a worldwide problem of enlarging significance as populations in industrialized countries become ever older. Prevention of fragility fractures requires a multifactorial approach especially in addressing lifestyle-related risk factors of fracture. Strategies that have been shown to be both feasible and effective include a physically active lifestyle, sufficient intake of calcium and vitamin D, and avoidance of smoking and excessive alcohol intake [1].

Bone tissue has the capacity to respond to exercise not only during skeletal growth but also in adulthood. However, the evidence based on bone mineral density (BMD) suggests that adult-age training tends mainly to preserve rather than increase BMD. Typical increases in BMD among adult exercisers are relatively small, typically a few percent on average [2, 3].

Regular impact-type loading (e.g., jumping or racket games) that creates high-magnitude loads at high rates from varying directions to the target bone may best improve structural strength during growth and young adulthood [4, 5]. There is also some evidence for the beneficial training effects on bone mass in older postmenopausal women, although in this group the training effects are mainly evident in terms of improved physical functioning and muscle force [6–10]. Active lifestyles involving brisk walking, stair-climbing up and down, dancing, and adult-age recreational gymnastics may be more suitable activities for the elderly, especially since these activities are widely available and relatively safe [11, 12].

Some studies have reported that the effect of exercise on bone is greatest when combined with high calcium intake, from either supplements or natural sources [13, 14]. Furthermore, the combination of calcium and exercise appears to be more effective in increasing bone mass or, at least, reducing bone loss in postmenopausal years than calcium alone [15, 16]. However, there is some dissent on this issue. Friedlander et al. [17] showed that calcium supplementation neither enhanced the exercise-induced bone benefit nor increased the bone mass in the absence of exercise. Nurzenski et al. [18] recently reported that high calcium intake and high level of habitual physical activity were positively associated with strength of the proximal femur. We have previously reported that high level of leisure-time physical activity and high calcium intake did not show a significant interaction despite their independent association with increased bone mass [19].

To examine this issue further we evaluated the long-term influence of previous calcium intake and leisure-time physical activity in this 10-year follow-up study on bone mass and strength and physical capacity in both younger premenopausal and older postmenopausal cohorts of women.

Subjects and Methods

Subjects

This study reports prospective data from pre- and postmenopausal women originally investigated 10 years ago [19]. Using a newspaper advertisement, we recruited 133 women in the age range of 25–30 years and 134 women between 60 and 65 years of age living in the city of Tampere, Finland, in the year 1995. Within age groups, those women were divided into four subgroups according to their concurrent levels of physical activity and calcium intake. Thus there were two physically active groups (PA^+; vigorous activity causing enhanced breathing and heart rate at least twice a week), with substantially different calcium intakes (abundant calcium intake [Ca^+; >1200 mg/day] and low intake [Ca^-; <800 mg/day]), and two physically inactive groups (PA^-; light or minimal daily physical activity causing only a light elevation of heart rate), with the above-noted contrast in calcium intake.

At baseline all women were healthy, fully ambulatory nonsmokers and none were on hormone therapy (HT). Altogether 219 (92 premenopausal and 127 postmenopausal) women participated in 5-year and 213 women participated in 10-year, follow-up measurements, 103 premenopausal (77% of the original cohort) and 111 postmenopausal (83% of the original cohort) women. None of the premenopausal women went through menopause during the follow-up period. Five of the postmenopausal women used HT at the 10-year measurement.

The study protocol was approved by the Ethics Committee of The Pirkanmaa Hospital District, and each participant gave her written informed consent prior to the measurements.

Measurements

All the following measurements were done at baseline and at 5- and 10-year follow-up time points.

Interview

Information on the participants' health, lifestyle (history of physical activity, use of alcohol), use of medication including HT, history of breastfeeding, and data on incident fractures during the follow-up time were collected in an interview.

Calcium Intake

Current daily dietary calcium intake was assessed by a 7-day calcium intake diary [20] and calculated by the validated Micro-Nutrica software (Social Insurance Institution, Helsinki, Finland). Information on use of calcium or other dietary supplements was obtained in an interview.

Physical Activity

Information on the subjects' lifetime physical activity was obtained with a standardized questionnaire and interview at baseline [19]. The original groups were maintained in the present analysis. In addition, current physical activity and possible changes from baseline to the time of the follow-up examination were determined with a questionnaire covering 1-year intervals. Each subject's daily walking distance was measured on 3 days (2 week days and a Sunday) with a pedometer.

Muscle Performance and Functional Capacity

The maximal isometric strength of the leg extensors and forearm flexors of the dominant side were measured by a strain gauge dynamometer (Tamtron, Tampere, Finland) [21], and cardiorespiratory fitness (estimated maximal oxygen uptake as VO_{2max}) was assessed by a standardized 2-km walk test [22]. In addition, the walking time for a 2-km walk was recorded to estimate general functional capacity. Cardiorespiratory fitness was measured for premenopausal women only: for postmenopausal women we used the 2-km walking time because the effect of concurrent cardiorespiratory medication on heart rate may have compromised the estimated oxygen uptake.

Bone Measurement

Bone mineral content (BMC; g) of the femoral neck and trochanter were measured with dual-energy X-ray absorptiometry (DXA; Norland XR-26; Norland Corp., Fort Atkinson, WI) according to our standard procedures [23]. Since the conventionally used areal bone mineral density (BMD) is a hybrid measure of bone size and volumetric apparent density, and thus somewhat complicated to interpret, BMC was chosen as the primary outcome measure. BMC reflects the amount of building material of the given bone site but, as such, does not provide specific information about the size, geometry, or structure of the given site [24]. These characteristics were estimated by the hip structure analysis (HSA) program (see below). In our laboratory, the in vivo precision (coefficient of variation) of these DXA measurements is about 1% [23]. The scanner was calibrated daily and its performance was monitored with daily phantom measurements [25]; no significant scanner drift occurred.

As noted above, in addition to conventional BMC analysis, the femoral neck DXA scans were analyzed using the HSA program developed by Beck et al. [26]. Measurements included bone cross-sectional area (CSA; cm^2), section modulus (Z; cm^3), and outer diameter (mm) at the narrowest section of the femoral neck. CSA denotes the cross-sectional area occupied by bone mineral, or in mechanical terms, the strength against axial compression [8], and Z denotes the structural strength against static bending, although as measured it only refers to bending in the image plane.

Statistical Analyses

Means and standard deviations (SD) were used as descriptive statistics. Linear mixed models with restricted maximum likelihood (REML) estimation were used to assess the mean differences and changes in bone and physical performance between the initial calcium and the initial physical activity groups during the follow-up. This type of analysis allows incorporation of incomplete data into the models. Analyses were adjusted for age, height, and weight by including the baseline values of these variables as covariates in all models. Three repeated measurements of each bone and physical performance measure (baseline and 5- and 10-year follow-ups) were used as dependent variables, and the calcium intake and physical activity groups and the time variable were factors. The compound symmetry was used as the covariance structure for repeated measurements.

Reported between-group differences in bone and physical performance during the follow-up correspond to differences in the mean level of three repeated measurements between the study groups. Each between-group difference in the change of bone and physical performance as a function of time was evaluated by analyzing the group–time interactions.

Relative mean differences between the groups and their 95% confidence intervals (CIs) were obtained from log-transformation of dependent variables and subsequent antilog transformation of the parameter estimates.

All statistical tests were two-sided and P-values < 0.05 were considered to be statistically significant. For the bone changes, when the 95% CI did not include zero, the difference was regarded as statistically significant at $\alpha = 0.05$.

Results

Group characteristics at baseline are given for premenopausal women in Table 1 and for postmenopausal women in Table 2. Among premenopausal women, the mean (SD) body weight increased by 5.0 (6.1) kg, with a large range, from −8.9 to 25.6 kg, but the body height was maintained. For postmenopausal women, the mean change in body weight was −0.2 (4.4) kg, with a large range, from −12.0 to 10.1 kg. The mean height loss was <1 cm in 10 years. At baseline all subjects were clinically healthy, and although none of the postmenopausal women were on HT at baseline, 17 of them had reported a short (max. 3-year) period of HT during menopause more than 5 years prior to

Table 1 Baseline group characteristics for premenopausal women: mean (SD)

Baseline	Ca^{+} PA^{+} ($n = 38$)	Ca^{+} PA^{-} ($n = 34$)	Ca^{-} PA^{+} ($n = 33$)	Ca^{-} PA^{-} ($n = 28$)
Age, years	28.2 (2.2)	28.7 (2.0)	27.5 (2.0)	28.3 (2.6)
Height, cm	166.7 (6.2)	167.8 (5.1)	166.1 (7.2)	166.3 (6.6)
Weight, kg	63.3 (9.3)	65.1 (8.8)	61.0 (7.4)	62.7 (9.2)
BMI, kg/m^2	22.8 (3.0)	23.1 (2.7)	22.1 (2.4)	22.7 (3.4)
Calcium intake, mg/day	1442 (325)	1298 (322)	655 (160)	655 (158)
Parity at baseline, *n*	0.5 (0.9)	1.0 (1.2)	0.1 (0.4)	0.7 (1.0)
Femoral neck BMC, g	3.17 (0.39)	3.05 (0.40)	3.12 (0.47)	3.07 (0.42)
Trochanter BMC, g	6.37 (0.86)	6.07 (0.81)	6.48 (1.09)	6.10 (0.98)
Narrow neck CSA, cm^2	3.07 (0.37)	2.96 (0.33)	2.99 (0.45)	2.93 (0.43)
Narrow neck *Z*, cm^3	1.47 (0.23)	1.44 (0.23)	1.43 (0.26)	1.47 (0.27)
Narrow neck outer diameter, mm	29.8 (2.3)	30.3 (2.2)	29.7 (2.1)	30.4 (2.6)
Daily steps, *n*	10,795 (4,760)	8,124 (2,842)	10,333 (4,412)	7,492 (1,991)
Leg extensors, kg/body weight	2.31 (0.44)	2.15 (0.34)	2.17 (0.38)	2.01 (0.27)
Arm flexors, kg	17.5 (2.9)	17.7 (3.5)	16.6 (3.7)	16.3 (3.0)
2-km walking time, min	15.3 (0.9)	16.2 (1.0)	15.3 (1.2)	16.8 (1.4)
VO_{2max}[a], ml/min/kg	40.0 (3.53)	36.8 (3.5)	40.2 (4.3)	35.9 (4.3)

[a] Estimated oxygen uptake, ml/min/kg

Table 2 Baseline group characteristics for postmenopausal women: mean (SD)

Baseline	Ca^{+} PA^{+} ($n = 38$)	Ca^{+} PA^{-} ($n = 42$)	Ca^{-} PA^{+} ($n = 23$)	Ca^{-} PA^{-} ($n = 31$)
Age, years	63.3 (2.0)	62.2 (1.9)	63.4 (1.9)	62.2 (1.8)
Height, cm	162.3 (5.9)	162.6 (6.0)	161.2 (4.2)	162.4 (6.4)
Weight, kg	68.5 (9.9)	69.0 (7.4)	68.1 (11.2)	70.2 (10.5)
BMI, kg/m^2	25.7 (3.1)	26.2 (2.9)	26.1 (4.1)	26.7 (3.3)
Calcium intake, mg/day	1530 (487)	1519 (471)	692 (122)	631 (162)
Parity, *n*	1.7 (1.2)	2.0 (1.8)	2.0 (1.2)	1.8 (1.4)
Femoral neck BMC, g	2.79 (0.51)	2.70 (0.32)	2.74 (0.32)	2.54 (0.41)
Trochanter BMC, g	5.97 (1.03)	5.78 (0.71)	5.94 (0.73)	5.60 (1.10)
Narrow neck CSA, cm^2	2.72 (0.52)	2.65 (0.34)	2.66 (0.29)	2.52 (0.39)
Narrow neck *Z*, cm^3	1.40 (0,33)	1.36 (0.25)	1.39 (0.19)	1.26 (0.30)
Narrow neck outer diameter, mm	32.2 (2.2)	31.7 (2.1)	31.2 (1.16)	31.3 (2.1)
Daily steps, *n*	10,606 (3,964)	8,848 (3,403)	10,740 (3,413)	7,514 (3775)
Leg extensor, kg/body weight	1.89 (0.26)	1.75 (0.28)	1.85 (0.24)	1.65 (0.25)
Arm flexors, kg	14.8 (3.0)	14.6 (2.7)	14.3 (2.0)	13.7 (2.2)
2-km walking time, min	17.3 (1.1)	17.8 (1.3)	17.3 (1.0)	18.7 (1.9)

baseline measurements. During follow-up nine women reported use of HT, and five of them were still on HT at the 10-year endpoint. Furthermore, six postmenopausal women had started a specific antiresorptive drug treatment. Forty-six premenopausal and 32 postmenopausal women reported decreased leisure-time physical activity, while 19 pre-menopausal and seven postmenopausal women reported increased physical activity. All women were nonsmokers and the use of alcohol ranged from abstainers to moderate users.

The baseline data in bone and fitness characteristics are given in Table 1 and 2, and Table 3 reports the age-, height-, and weight-adjusted mean differences between the calcium intake and the physical activity groups during the 10-year follow-up time. Since there was no significant interaction between physical activity and calcium intake with respect to any bone variable, the main effects of physical activity and calcium intake on the bone variables are described separately. Among premenopausal women, there were no significant mean differences in bone mass or

Table 3 Age-, height-, and weight-adjusted mean percentage differences between the calcium intake (Ca^+ and Ca^-) and the physical activity (PA^+ and PA^-) groups among pre- and postmenopausal women during the 10-year follow-up period

	Mean % difference[a] (95% CI)			
	Premenopausal women ($n = 133$)		Postmenopausal women ($n = 134$)	
	Ca^+ versus Ca^-	PA^+ versus PA^-	Ca^+ versus Ca^-	PA^+ versus PA^-
Femoral neck BMC	−0.3 (−4.0 to 3.6)	3.8 (−0.1 to 7.8)	4.2 (−0.2 to 8.8)	6.9 (2.2 to 11.8)
Trochanter BMC	−0.6 (−4.7 to 3.5)	6.7 (2.4 to 11.3)	2.7 (−1.6 to 7.2)	5.5 (0.9 to 10.3)
Narrow neck CSA	1.4 (−2.8 to 5.8	3.7 (−0.6 to 8.2)	3.8 (−0.9 to 8.7)	6.8 (1.9 to 12.0)
Narrow neck Z	−0.5 (−5.6 to 4.9)	2.0 (−3.2 to 7.6)	4.4 (−2.1 to 11.4)	9.6 (2.5 to 17.1)
Narrow neck outer diameter	−0.7 (−2.9 to 1.6)	−0.9 (−3.2 to 1.4)	1.1 (−0.9 to 3.1)	1.0 (−1.0 to 3.1)
Leg extensors	5.4 (0.0 to 11.2)	3.3 (−1.8 to 8.9)	3.1 (−1.9 to 8.4)	10.2 (4.7 to 16.0)
Arm flexors	7.6 (2.1 to 13.4)	−1.0 (−6.0 to 4.4)	4.7 (−0.5 to 10.1)	4.4 (−0.9 to 10.0)
2 km walking time, min	−1.5 (−3.6 to 0.7)	−5.6 (−7.6 to −3.5)	−1.0 (−3.8 to 1.7)	−6.0 (−8.6 to −3.2)
VO_{2max} [b]	1.7 (−1.3 to 4.9)	8.6 (5.3 to 11.9)		

[a] Linear mixed model for repeated measurements (baseline, 5-year, and 10-year), adjusted for age, height, and weight at baseline

[b] Estimated oxygen uptake, ml/min/kg

strength of the proximal femur between the high- and the low-calcium intake groups. Proximal femur BMC was on average 3.8% (femoral neck) to 6.7% (trochanter) greater in the PA^+ group compared with the PA^- group, being statistically significant only for trochanter BMC (Table 3). As regards CSA and Z, the differences did not reach significance.

Among postmenopausal women, differences between the Ca^+ and the Ca^- groups in proximal femur BMC did not reach statistical significance. Physical activity seemed to benefit the proximal femur; the mean BMC differences between the PA^+ and the PA^- groups were from 5.5 (trochanter) to 6.9% (femoral neck) higher. Mean differences in CSA and Z between the Ca^+ and the Ca^- groups were about 4%, while the respective differences between the physical activity groups were nearly two times greater (Table 3).

Bone mass and strength appeared to decline with time in both premenopausal and postmenopausal women, while the baseline differences were mainly maintained irrespective of calcium intake or level of physical activity, with one exception: there was a significant interaction between calcium intake and time in premenopausal women. The Ca^+ group showed a smaller decline in BMC compared with the Ca^- group at the trochanter ($P = 0.002$) (Figs. 1 and 2).

The mean BMC decrease in 10 years among premenopausal women was 3.8% at the femoral neck and 3.7% at the trochanter, signifying an annual bone loss of about 0.4%. The respective values were twice as high for the postmenopausal women, being 7.6 and 9.3% at the femoral neck and trochanter, approximating annual changes from 0.8 to nearly 1%, respectively. Changes in bone strength were marginal in young women, but both axial and bending strength declined among older women (Figs. 1 and 2). Narrow neck outer diameter showed no detectable change in 10 years among the premenopausal women (0.2% [−1.7 to 2.0%]), but there was a slight increase of 1.1% (0.3% to 1.9%) among the older women.

Comparing the mean differences in physical fitness during the follow-up, the physically active pre- and postmenopausal women had better general physical capacity than their sedentary counterparts: their 2-km walking time was about 6% faster than that in the PA^- group. There was no significant difference in isometric leg extension or arm flexion muscle strength among the younger women, while in the older age group isometric leg extension strength was 10% better in the PA^+ group than in the PA^- group (Table 3). Physical performance declined quite linearly in both age groups, with no statistically significant differences between groups. The exception was walking speed; the 2-km walking time was maintained among premenopausal women, while among postmenopausal women the decline was particularly distinct during the last 5 years (Fig. 3).

As regards the bone fractures during the follow-up time, altogether 15 women had sustained bone fracture. Four premenopausal women had suffered one bone fracture (two forearm, one finger, and one metatarsal stress fracture), and one woman had suffered several fractures (forearm, rib, and ankle) in a horse-riding accident. All five of these women were in the low-calcium intake group. Ten postmenopausal women (one in the Ca^+ PA^+ group and three in each of the other groups) had sustained a bone fracture (five forearm, two rib, one knee, one ankle, and one metatarsal fracture).

Discussion

This 10-year follow-up showed that bone mass and strength with respect to axial loads in the proximal femur declined

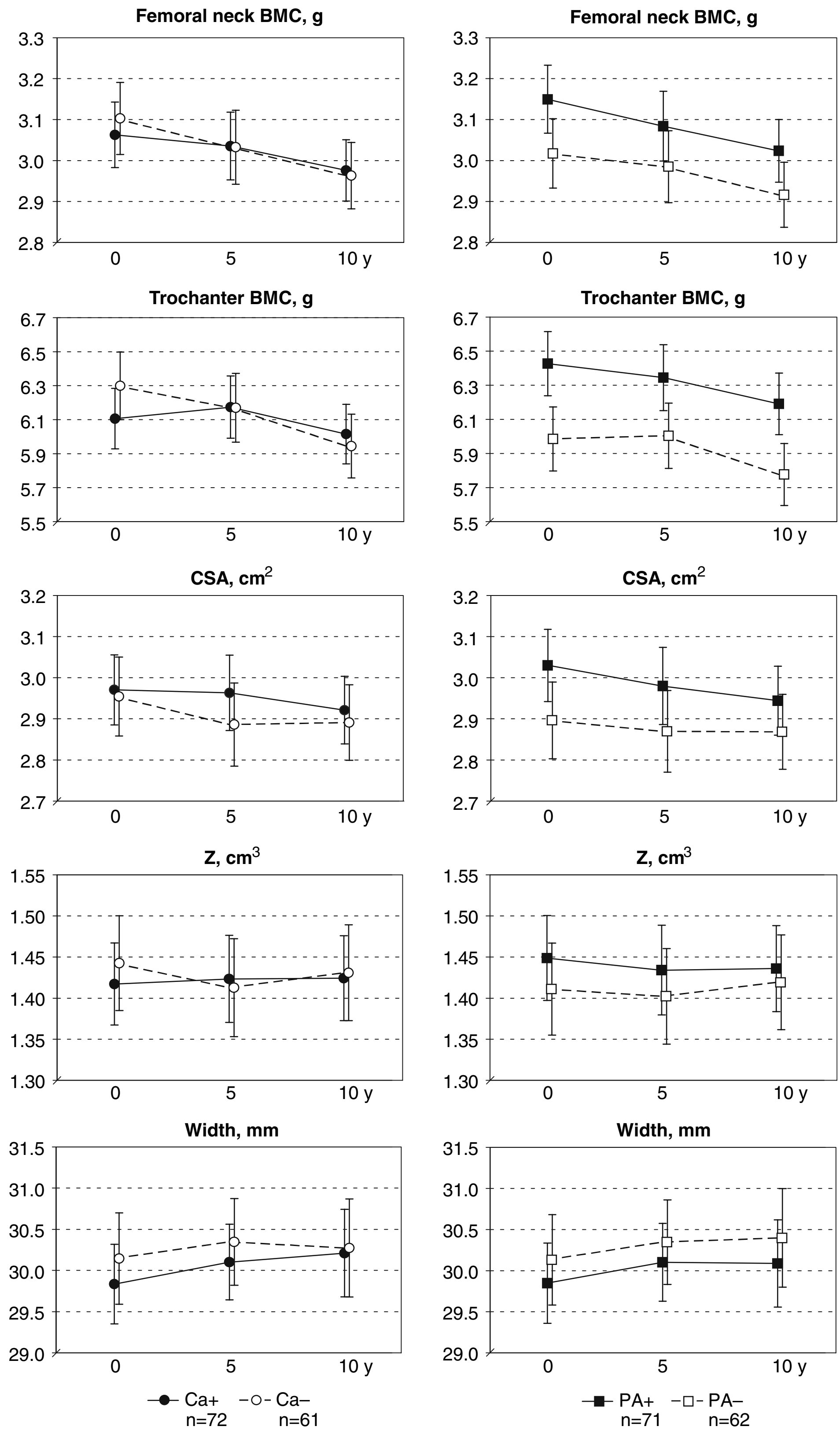

Fig. 1 Age-, height-, and weight-adjusted mean values in femoral neck and trochanter BMC and in axial strength (CSA) and bending strength (Z) at the narrowest section of the femoral neck in premenopausal women at baseline and at 5- and 10-year follow-up time points($n = 133$). Results are shown separately for calcium intake (left) and physical activity (right) groups. The bars represent 95% confidence intervals

among both pre- and postmenopausal women, but the initial differences between the two physical activity and the two calcium intake groups remained over time. We did not detect an interaction between calcium intake and physical activity, but in premenopausal women, high calcium intake seemed to prevent bone loss at the trochanter.

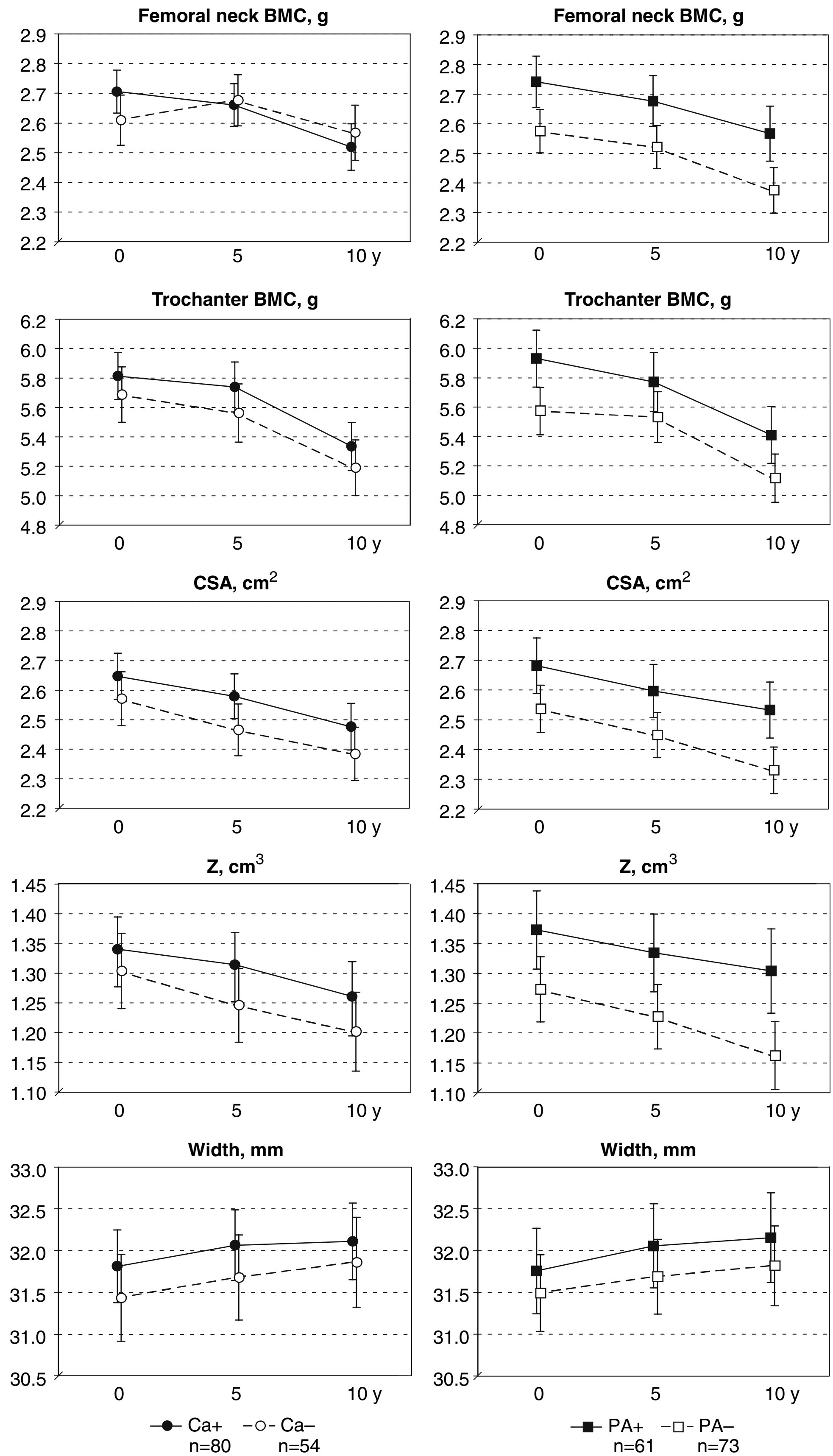

Fig. 2 Age-, height-, and weight-adjusted values of femoral neck and trochanter BMC and of axial strength (CSA) and bending strength (*Z*) at the narrowest section of the femoral neck in postmenopausal women at baseline and at 5- and 10-year follow-up time points ($n = 134$). Results are shown separately for calcium intake (left) and physical activity (right) groups. The bars represent 95% confidence intervals

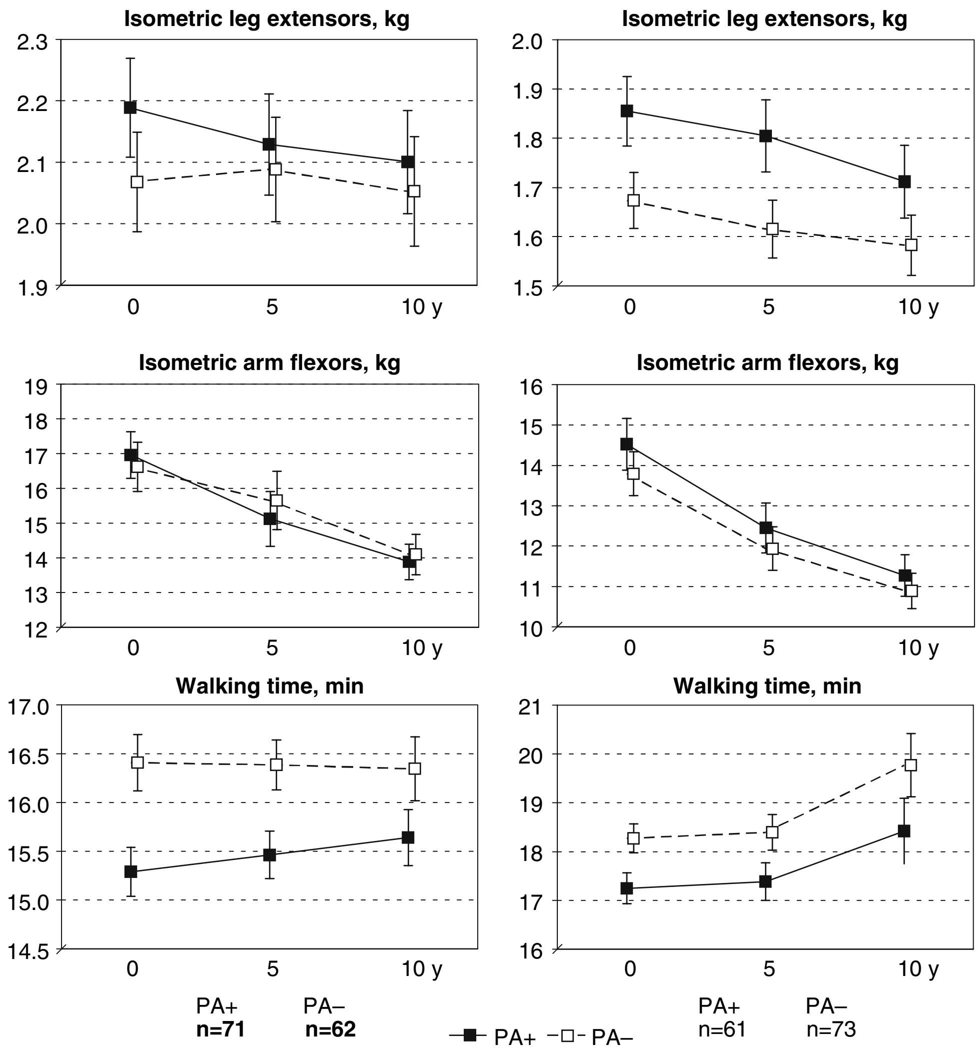

Fig. 3 Age-, height-, and weight-adjusted values of isometric muscle strength of leg extension (per body weight) and forearm flexion and 2-km walking time in premenopausal (left; n = 133) and postmenopausal (right; n = 134) women at baseline and at 5- and 10-year follow-up time points. Results are shown only for physical activity groups. The bars represent 95% confidence intervals

Longitudinal studies have suggested annual losses in hip BMD from 0.35 to 1.14% among pre- and postmenopausal women [27–31]. We found an annual decline of about 0.4% in bone mass among premenopausal women, and double that among older postmenopausal women. Recently we reported a mean decline in proximal femur bone mass of about 0.5% per year among similarly aged postmenopausal women [11], but in that study about 40% of the subjects were on HT. HT has been shown to have a significant protective effect on bone mass [31–33].

We found only a slight decline in axial strength and no change in section modulus (bending strength) among premenopausal women, while both CSA and *Z* declined among postmenopausal women. This finding accords with results of Beck et al. [26]. Although the design of their NHANES study was cross sectional, the results suggest that despite the declining BMD, the bending strength of the femoral neck is virtually maintained until the fifth decade of age in women, and then declines at a slower rate than does bone mass. The femoral neck diameter was similar between the physical activity and the calcium intake groups, but the postmenopausal group showed a slight mean widening during the 10-year follow-up. This is important, as even a minor increase in bone diameter can help to maintain bone rigidity against bending [34].

Exercise interventions have shown increased bone mass and bending strength in young adulthood [35–38], while in postmenopausal women the benefits have been more limited [1–3, 6–8, 35–37, 39–41]. Not only the frequency and duration of physical activity but also the intensity are important for both bone and fitness preservation. To be able to maintain the achieved level of physical performance, the intensity of training should be at least maintained with aging. However, as people age, not only the intensity of their physical activity, but also the variety of the activity narrows, and the musculoskeletal system becomes loaded more exclusively by slow-speed activities; e.g., walking instead of running and swimming instead of aerobics. Our results showed that baseline between-group differences in physical performance were maintained but that the general physical fitness declined in all groups, with a greater decline among older women. In premenopausal women, the declines in physical activity seemed to be due mainly to circumstantial factors (e.g., working situation or family reasons), while postmenopausal women reported less change in time invested in physical activity but more change in its type or intensity.

Bone accrual and maintenance requires sufficient amounts of many essential nutrients, but calcium has received the greatest attention because it is the major component of skeletal mineral. There is no doubt that calcium is important for bone health; persons with a high calcium intake have greater bone mass than persons with a habitually low intake [13, 42, 43], and many randomized controlled trials have corroborated the observational findings of a causal connection between low calcium intake and bone fractures [44–47]. Typically a person who has more bone in young adulthood also appears to have more bone in older age, and calcium intake may be one of the crucial factor in this respect.

We did not find any difference in bone mass or strength between high- and low-calcium intake groups in premenopausal women, whereas there were slight differences in postmenopausal women. These findings, however, do not justify the conclusion that the difference increases with age, or that young women with a high calcium intake, who maintain it to old age, will have stronger bones in their seventies. However, we found an interesting interaction between calcium intake and time for the trochanter in premenopausal women. The younger and older women represent two different cohorts with different life histories, and only follow-up of the younger group for an additional 20–30 years would be able to show whether the mean difference between the calcium intake groups increases further. However, it is important to recognize that the calcium requirement appears to increase with age but that the ability to compensate for an inadequate dietary intake seems to decline with age [48].

There is some evidence that physical activity and calcium do not act independently of each other. In her review Specker concluded that a positive effect of physical activity appears to exist only with daily calcium intakes >1,000 mg, and the beneficial effect of a high calcium intake appears to be present only in physically active groups [14]. This is a question that has not been intensively explored. Some cross-sectional results have shown the greatest bone mass in women when both calcium intake and level of physical activity are high [18, 43]. Physically active older women with a high calcium intake had stronger bones than their inactive counterparts with a low calcium intake. Furthermore, these factors seemed to have an additive effect on bone strength [18]. However, not all results regarding effects of calcium and exercise on bone mass are consistent. Prince et al. showed that calcium supplementation with exercise reduced bone loss at the hip site among elderly women [16], but in another study calcium supplementation, but not exercise, was effective in reducing bone loss at the hip among elderly Chinese women with a low baseline calcium intake [49]. On the other hand, exercise can be beneficial in improving muscle strength and coordination, hence preventing falls and fractures [49]. In contrast, exercise was shown to have a positive effect on bone mass among young women, while calcium intake did not [17, 50]. In the previous follow-up measurements, 5 years earlier, we reported that both high calcium intake and high level of physical activity were associated with a smaller decrease in proximal femur bone mass in both age groups [51, 52].

Regular exercise has been shown to result in lower fall risk due to better balance, improved muscle power, and faster reaction time [53–55], and a lower incidence of falls is likely to result in fewer fractures. We were not able to evaluate falls during the follow-up time in our study. In premenopausal women, high physical activity may increase the propensity for falls and, when accompanied by a low calcium intake, for fractures. Indeed, most of the young women's fractures in this study had occurred during physical activity (snowboarding, horseback riding, and the metatarsal stress fracture due to intensive dance training) and exclusively among those who had a low calcium intake. The 10 postmenopausal women who had suffered a bone fracture were distributed equally between the two calcium intake groups and the two physical activity groups; the most common type was distal forearm fractures caused by falling on icy streets in wintertime. Even though not obvious in this study, physical activity, better balance, and greater muscle strength may protect against hip and other fractures later in life by preserving bone mechanical strength and reducing the risk and severity of falls [55]. Of clinical interest, women with fractures seemed to have a lower baseline bone mass and strength (data not shown), but given the small size of this study, this finding cannot be particularly stressed.

In addition to its obvious advantages, this 10-year follow-up study also has some methodological limitations. Evaluation of the proximal femur structure was based on two-dimensional DXA data [26, 56]. Also, we were not able to measure directly the intensity of physical activity of the participants, and estimates of physical performance could only indirectly describe the possible changes in this trait. Estimation of calcium intake is also difficult due to lack of direct and exact methods; the calcium intake diary used in this study most likely underestimated the total calcium intake [19, 20]. Most likely there were unidentified increases as well as decreases in both physical activity and calcium intake during the 10-year follow-up. Care must also be taken when generalizing the results, since our sample size was somewhat limited and the participants were not selected randomly. It is also likely that the Finnish population may be more physically fit and less heterogeneous in this regard than populations with a greater number of more sedentary individuals. It must also be recognized that DXA measurements are relatively crude and may not be adequately sensitive to detect subtle effects.

In conclusion, the beneficial effects of physical activity and calcium intake on bone mass and strength seem to be a continuum from young age, with the accrual and maintenance of bone mass and strength, to older age, with a reduction in the rate of bone loss. High calcium intake seemed to slow the decline in trochanter BMC in premenopausal women. Higher physical activity, in turn, was beneficial for mass and geometric strength of the proximal femur, particularly among older women. Our results thus support the notion that women should be encouraged to take a sufficient amount of calcium and should engage in regular leisure-time physical activity.

Acknowledgments The authors thank the Medical Research Fund of Tampere University Hospital and the Finnish Ministry of Education for financial support.

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