One Year of Oral Calcium Supplementation Maintains Cortical Bone Density in Young Adult Female Distance Runners

Kerri M. Winters-Stone and Christine M. Snow

We conducted a double-blind, placebo-controlled, randomized trial to determine whether 1 year of supplemental calcium intake would augment hip (greater trochanter, GT, femoral neck (FN), total hip (TH)), spine (LS), and femoral mid-shaft (Fmr) BMD in female distance runners. Twenty-three women (age: 23.7 ± 4.7 yrs, height: 165.6 ± 6.3 cm, weight: 55.7 ± 6.1 kg) were randomly assigned to receive either 1000 mg/d of supplemental calcium (N = 13) or placebo tablets (N = 10) for 1 year. BMD was determined by DXA (Hologic 1000-W) and tablet compliance by self-report logs. Compliance averaged 79% and 71% for supplement and placebo groups, respectively. Calcium supplementation did not affect hip or spine BMD, but did prevent loss at the femoral mid-shaft (GT: –0.5% vs. 0.2%, FN: 0.9% vs. 1.1%, TH: –0.3% vs. 0.2%, LS: 0.3% vs. 1.2%, Fmr: 0.1% vs. –1.8%, for calcium vs. placebo, respectively).

We conclude that the addition of 800 mg/d of supplemental calcium to the diet of young adult female distance runners with habitual calcium intakes of ~1000 mg/d, prevents cortical but not trabecular bone loss.

Key Words: nutrition, premenopausal, women, athletes, bone, osteoporosis

Introduction

Competitive female athletes who participate in impact sports typically have higher bone mineral density (BMD) than their non-athletic counterparts. Specifically, gymnasts, basketball players, and volleyball players typically have BMD values up to 35% greater than sedentary controls (14, 33, 35). However, despite the nature of their activity, female distance runners do not possess comparably high BMD (24, 35, 38, 45). In fact, BMD in eumenorrheic female runners is similar to that of inactive controls and, in runners who have amenorrhea, spinal BMD is 5–15% below that of non-runners (7, 12).

Hip and spine bone mass are typically accrued until the mid or end of the third decade, respectively, with the onset of gradual loss at each site occurring about 10 years after peak accrual (20). Peak bone mass is genetically determined, and inactivity...
and/or insufficient calcium intake can impair optimal skeletal development (19). Failure to achieve peak bone mass in early adult years may hasten the onset of osteoporosis (31). In endurance athletes, low BMD may also contribute to the occurrence of stress fractures, which are reportedly higher among runners compared to other athletes (3). The sub-optimal BMD development evident in female distance runners may be speculatively linked to several factors, including lower circulating estradiol levels, repeated microtrauma associated with overtraining, and poor nutrition (3, 8, 10, 12, 30, 40, 45). As such, general recommendations for improving bone health in athletes include maintenance of normal menstrual cycles or oral contraceptive use, reductions in training volume, and increased dietary energy and/or calcium intake to or above the currently recommended adequate intake (AI) of 1000 mg/d for adult women aged 19 and above (17, 21). However, athletes may resist oral contraceptive use, increased energy intake, or reduced training for fear of weight gain and/or fitness losses that might affect performance. Thus, oral calcium supplementation may provide a simple and effective means for optimizing skeletal health in young adult female distance runners.

In non-athletic populations, calcium supplementation has been shown to increase bone mass in children and to slow bone loss in both pre- and postmenopausal women (1, 5, 9, 13, 23, 34). The current AI for calcium in young adult women is 1000 mg/d, yet habitual calcium intake in this age group often falls short of recommended values (600 mg/d; 12, 21). However, the effect of calcium supplementation on BMD in female distance runners is poorly understood. Thus, we conducted a double-blind, placebo-controlled, randomized trial to determine whether 1 year of supplemental calcium intake in female distance runners would augment BMD at the hip and spine, clinically relevant fracture sites of high trabecular content, and/or at the femoral mid-shaft, a primarily cortical region similar in composition to typical stress fracture sites like the tibia.

**Methods**

**Subjects**

Participants were recruited through advertisements in local newspapers and regional track and field newsletters and through contacts within the local running community. Eligible participants were between 18 and 35 years of age; ran a minimum of 10 miles per week and competed in regional or national running events; were free of diseases known to affect bone metabolism; and were not taking medications known to alter bone or calcium metabolism (i.e., glucocorticoids, thyroid hormone, parathyroid hormone). Menstrual status was not used as an inclusion criterion but rather was tracked and considered in statistical analyses. Oral contraceptive use did not preclude participation in this study, since its effect on BMD in premenopausal women is inconclusive (22, 29, 32, 33). Women who were currently taking calcium supplements were not precluded from participation, and their supplemental calcium was figured into their dietary intake analyses. A formal sample size calculation using ANOVA to detect a 1% difference in 1-year BMD changes between groups yielded an estimate of 17 subjects per group. Factoring in 20% attrition, we aimed to recruit a minimum sample size of 20 per group. A total of 51 women met the inclusion criteria and gave written informed consent to begin the 1-year intervention trial.
Experimental Design

Upon entry into the study, women were randomly assigned to receive either a daily calcium supplement \((n = 26)\) or placebo \((n = 25)\) and followed for 1 year. Neither the subjects nor the investigators were aware of group assignment until completion of the study. The calcium supplement group ingested a total dose 1000 mg of calcium carbonate per day in the form of chewable tablets (500 mg/tablet), once in the morning and once in the evening. The placebo group ingested two sugar-based placebo tablets daily, one in the morning and one in the evening. The timing of the supplement doses was separated by an 8–12 hour period in order to maximize absorption of calcium across the gut (18). SmithKline Beecham, Inc., provided both supplement and placebo tablets.

Following the baseline measurement, supplement or placebo tablets were distributed to each participant who was retested 12 months later. At the initial visit, each subject completed questionnaires on the following: medical and gynecological history, habitual physical activity and training mileage, and a self-report 4-day food record. Each subject then underwent a series of four BMD measurements. The second visit included BMD testing and collection of 4-day dietary and menstrual cycle records only.

Compliance

Subjects were provided with monthly logs on which to track their compliance to tablet consumption. Subjects simply checked a box for each day that they took their tablets. Monthly logs were collected at the halfway point and at the conclusion of the trial. Based on the monthly logs of tablet consumption, the compliance averaged 75%, and the compliance rate did not differ between groups (79% for supplement and 71% for placebo, respectively).

Bone Mineral Density and Anthropometry

Bone mineral density (BMD: g/cm²) of the greater trochanter, femoral neck, lumbar spine \((L_2-L_4)\), and femoral mid-shaft was measured via DXA (Hologic QDR 1000-W, software v. 4.74). The femoral mid-shaft scans were performed using the spine scan mode. The mid-shaft of the femur was located by palpating the greater trochanter and the lateral femoral condyle and beginning the scan at a distance one third of the total femoral length from the greater trochanter and then scanning one third of the total femoral length. Lean and fat masses were determined from whole body scans. In-house coefficients of variation (CV), determined on a sub-sample of women similar to our study population, are < 1.0% for regional bone measures and < 1.5% for body composition measures. Height and weight were measured without shoes, in standard dress clothing via a wall-mounted stadiometer to the nearest 0.1 cm and via a digital scale to the nearest 0.1 kg, respectively. Height was only measured at baseline, while weight was measured at baseline and 12 months.

Four-Day Food Records

Subjects were given 4-day food logs to be completed as closely as possible to the time when they were tested in the laboratory. This method has been shown to be a valid measure of habitual nutrient intake (4). Subjects were asked to record all food,
beverage, and supplement intake over a consecutive 4-day period, including 2 weekdays and 2 weekend days. Subjects were instructed to be as accurate and as honest as possible when recording the type and amount of food or beverage consumed. Subjects were shown food models of typical portion sizes for various types of foods in order to improve their accuracy when recording amounts consumed. Collected records were analyzed with the Food Processor II nutrient analysis software program (v. 2.2; Salem, OR, USA) for the following: total energy (kcal), carbohydrate (g), protein (g), fat (g), calcium (mg), and phosphorous (mg).

**Statistics**

Data were analyzed only for those subjects with complete data sets for the entire 12-month intervention. All values are expressed as mean ± standard deviation, except graphs where data are expressed as mean ± standard error of the mean. Dependent measures were examined to determine whether they met the assumptions of normality, linearity, and homogeneity of variance. Initial differences between groups were determined using unpaired t tests for normally distributed data and Mann-Whitney U tests for non-normally distributed data. As data for dependent measures met the assumptions for normality, group differences were evaluated by separate univariate ANOVA for each dependent measure, comparing mean score difference over time between groups. All statistical analyses were performed with the SPSS statistical software program, version 10.0, with a two-tailed significance criterion set at p < .05.

**Results**

Since delivery of supplements by the supplier was delayed by 7 months, 14 women dropped out of the study due to lack of interest. An additional 14 women dropped out over the 12-month trial period due to the following reasons: stopped running due to injury (N = 3), relocation outside of study area (N = 3), unwillingness/inability to travel to the study site (N = 4), or reduced interest in the study (N = 4). Thus, complete data sets were available for 23 women who completed the 12-month trial, and all analyses are based on these 23 women.

Women in the two study groups were similar for age, height, weight, menstrual cycle status, and training mileage (Tables 1 and 2). While height and weight remained stable in both groups over time, percent body fat increased in the placebo group (+1.1% ± 1.5%), and this increase was significantly different from the supplemented group who experienced a slight decrease (−0.6% ± 1.7%). Based on the previous year’s menstrual history, 3 women in the placebo group and 1 woman in the supplement group were classified as oligomenorrheic (4–10 menstrual cycles per year) at initiation of the study. Analysis of data excluding oligomenorrheic subjects did not alter statistical outcomes, and thus eumenorrheic and oligomenorrheic subjects were grouped together. Menstrual cycle status did not change over the course of the study.

**Bone Mineral Density**

Compared to the DXA reference database, average BMD values across groups at the spine and hip were 4% below and 1% above age-matched women, respectively.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Calcium</th>
<th>Placebo</th>
<th>Calcium</th>
<th>Placebo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>24.0 ± 4.2</td>
<td>25.1 ± 4.2</td>
<td>25.1 ± 4.8</td>
<td>26.0 ± 5.0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>166.3 ± 4.7</td>
<td>—</td>
<td>164.9 ± 7.8</td>
<td>—</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>57.2 ± 4.9</td>
<td>56.3 ± 4.3</td>
<td>54.1 ± 7.2</td>
<td>54.8 ± 7.2</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>16.7 ± 3.6</td>
<td>16.4 ± 4.3*</td>
<td>16.2 ± 2.8</td>
<td>17.3 ± 3.4</td>
</tr>
<tr>
<td>BMD (g/cm²)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Total hip</td>
<td>0.968 ± 0.096</td>
<td>0.965 ± 0.096</td>
<td>0.961 ± 0.112</td>
<td>0.962 ± 0.114</td>
</tr>
<tr>
<td>Femoral neck</td>
<td>0.908 ± 0.119</td>
<td>0.915 ± 0.094</td>
<td>0.875 ± 0.096</td>
<td>0.884 ± 0.115</td>
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<td>Greater trochanter</td>
<td>0.740 ± 0.101</td>
<td>0.736 ± 0.101</td>
<td>0.736 ± 0.067</td>
<td>0.737 ± 0.059</td>
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<tr>
<td>Lumbar spine</td>
<td>1.007 ± 0.105</td>
<td>1.010 ± 0.105</td>
<td>1.014 ± 0.088</td>
<td>1.026 ± 0.080</td>
</tr>
<tr>
<td>Femoral mid-shaft</td>
<td>1.791 ± 0.108</td>
<td>1.791 ± 0.101*</td>
<td>1.843 ± 0.123</td>
<td>1.810 ± 0.123</td>
</tr>
</tbody>
</table>

*Change over time differed between groups, p < .05.

Note. Data are presented as mean ± SD. Only baseline height measured.
Age-based norms were not available for mid-shaft femoral BMD; thus, we could not determine age-normative skeletal status at this site. Baseline BMD was not significantly different between groups at any site. Calcium supplementation failed to affect either hip or spine BMD (Figure 1). However, increased calcium intake maintained femoral mid-shaft BMD in the supplemented group compared to a decrease at this site in the placebo group ($p = .02$). Adjustment of BMD responses for significant changes in percent body fat via analysis of covariance did not alter statistical outcomes.

### Dietary Analysis

Total energy intake was below that expected for athletic women; however, the macronutrient composition of the diet (high carbohydrate and low fat) was typical of endurance athletes (Table 2; 6, 37). Dietary calcium intake was at or slightly above the AI for women of this age group (1000 mg/d; 21). No significant group differences were observed for any dietary variable. In addition, there were no significant changes in dietary intake or composition over the course of the trial. With the addition of the calcium supplement weighted by pill compliance, supplemented women consumed approximately 800 mg above their habitual calcium intake and 500 mg more calcium than controls (1794 mg/d vs. 1294 mg/d).

### Discussion

To our knowledge, we are the first to report results of a randomized placebo-controlled trial of calcium supplementation in young adult female endurance athletes. To date, the majority of calcium supplementation studies have been conducted in children, older adult premenopausal women, or postmenopausal women. As skeletal

<table>
<thead>
<tr>
<th>Variable</th>
<th>Calcium ($n = 13$)</th>
<th>Placebo ($n = 10$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training volume (mi/wk)</td>
<td>34.1 ± 6.7</td>
<td>41.4 ± 13.7</td>
</tr>
<tr>
<td>Total energy (kcal/d)</td>
<td>1514 ± 552</td>
<td>1512 ± 525</td>
</tr>
<tr>
<td>Carbohydrate (g/d)</td>
<td>230 ± 97</td>
<td>224 ± 93</td>
</tr>
<tr>
<td>Protein (g/d)</td>
<td>66 ± 28</td>
<td>71 ± 45</td>
</tr>
<tr>
<td>Fat (g/d)</td>
<td>37 ± 13</td>
<td>36 ± 12</td>
</tr>
<tr>
<td>Calcium (mg/d)</td>
<td>1006 ± 454</td>
<td>1294 ± 1263</td>
</tr>
<tr>
<td>Phosphorous (mg/d)</td>
<td>1232 ± 508</td>
<td>1545 ± 1205</td>
</tr>
<tr>
<td>Average menses in previous year</td>
<td>10.2 ± 2.9</td>
<td>11.2 ± 1.9</td>
</tr>
<tr>
<td>Oligomenorrheic (#)</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Note. Data are presented as mean ± SD.
development continues into the third decade, it is important to determine the efficacy of easily adaptable behaviors to promote skeletal health in young adult women through soundly designed interventions. Contrary to expectations, female runners possess a skeletal status no better than their sedentary counterparts, and suboptimal nutrition may be a likely contributor (24, 35, 38, 45). The repetitive nature of distance running may increase bone turnover at loaded sites in an attempt to repair microdamage caused by excessive strains (28). The calcium requirements to sustain high remodeling rates from repeated loading of cortical bone sites may be slightly greater than that required to maintain less frequently loaded and/or trabecular sites (27). Thus, while the habitual intakes in both groups were adequate according to current recommendations (21), it is possible that supplementation brought the calcium intake of our intervention group into the optimal range to prevent cortical bone loss that may be associated with calcium insufficiency in the face of repetitive strains in cortical bone.

Limitations of this study warrant mention. Our study suffered 50% attrition prior to the supplementation period, thus reducing our sample size and power to detect significant differences. The initial attrition is in part a consequence of the 7-month delay in delivery of the supplement and placebo from our supplier, while attrition during the study period was largely due to non-study related factors, such as relocation or injury, rather than disinterest attributable to the delay in supplement delivery. Compliance among remaining participants was high, indicating that athletes are amenable to supplementation, particularly if begun when interest is initially
expressed. Another limitation was incurred by the initial nutritional status of our subjects. The habitual calcium intake of our subjects was initially adequate, particularly in the placebo group (1294 mg/d), and this likely accounted for the differences in actual calcium intake between groups during the study being only 500 mg compared to the desired 1000 mg, as originally designed. Furthermore, it is also possible that initial calcium intakes were underestimated due to under-reporting, as evidenced by suspiciously low total energy intakes that are incompatible with the weight and running mileage of our subjects. Underreporting is a common saboteur of dietary recall accuracy in women of this age group (36). Had intakes for both groups been similar to the typical 600 mg/d reported for young women (15), or had the group differences in actual intake during the study been larger, we might have seen an effect of supplementation at other bone sites.

The aim of this study was to increase BMD at clinically important skeletal sites in young adult female distance runners through simple calcium supplementation. Results from our double-blind, placebo-controlled trial showed that 1 year of calcium supplementation did not affect hip or spine BMD, but did prevent a near 2% loss of bone at the femoral mid-shaft. Meta-analysis of randomized trials of calcium supplementation in slightly older non-athletic premenopausal women suggests that supplementation of 1 g/d prevents the expected 1% per year loss of bone at both cortical and trabecular skeletal sites, except the ulna (44). Reports from preliminary proceedings (published abstracts) of calcium supplementation trials in young adult female runners have yielded equivocal results that appear to be dependent upon the specific skeletal site. One year of calcium supplementation (1500 mg/d) failed to produce gains at skeletal sites containing high proportions of trabecular bone (proximal femur and spine) in runners compared to a placebo group (43). Drinkwater (1992) reported increases in BMD of the predominantly cortical tibial shaft from high calcium supplementation (1500 mg/d) in young female distance runners but no changes at the hip or spine. Similarly, we report a significant maintenance of femoral mid-shaft BMD from 800 mg/d of calcium supplementation but no effect at the hip or spine. It has been theorized that calcium intake has a greater impact on cortical than trabecular bone (27), thus explaining the lack of effect observed at the spine or hip. Calcium is considered a threshold nutrient in adulthood, and the reported threshold in adult women is ~1000 mg (25). Thus, it is possible that the additional calcium in our supplemental group that brought their daily intake above the recommended range could not increase bone mass at primarily trabecular bone sites but could prevent losses occurring at cortical sites.

It is well accepted that adequate calcium intake during growing years is essential for optimal skeletal development, while sufficient calcium intake during adult years is important for bone maintenance. Bone mineral density of adults is largely dependent upon the development of peak bone mass during adolescence and early adulthood (2, 39), and a decrease in peak bone mass is likely to increase the risk of fracture in later years (31). The timing of attainment of peak bone mass is estimated to occur between the ages of 16 and 28 years and, while genetically determined, the ability to fully express that genetic potential is dependent upon adequate environmental factors such as mechanical loading and mineral availability (16, 20, 33, 41). Thus, particularly important times to promote behavior that maximizes bone gains and minimizes losses are from the period of longitudinal growth through young adulthood. Cross-sectional and retrospective studies report that both
weight-bearing activity and lifetime calcium intake independently predict peak BMD (26, 42). The runners in our study, however, did not demonstrate BMD any greater than age-referenced norms, a finding corroborated by others (24, 35, 38, 45). The apparent inability to increase BMD through activity in these athletes cannot be addressed by our study; however, we did demonstrate that calcium supplementation offsets cortical bone loss in young female runners. Both cortical and trabecular bone loss occur with advanced age and contribute to skeletal fragility at appendicular and axial sites (27). Age-related loss of trabecular bone is similar between men and women, but women lose cortical bone at faster rates, and this may explain the disparity in fracture incidence between genders. Thus, calcium supplementation importantly minimized cortical bone loss in female endurance athletes in whom optimal skeletal development, during young adult years, is critical to ensure skeletal health in later life. Given our small sample size, however, it is important that these findings be confirmed in a larger sample before dietary recommendations are made.

References


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