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# High-Impact Exercise Promotes Bone Gain in Well-Trained Female Athletes

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## ABSTRACT

**Maximizing peak bone mass, as well as reducing its loss after menopause, is important for the prevention of osteoporosis. One mode of activity, gymnastics training, invokes high impact loading strains on the skeleton which may have powerful osteogenic effects. To examine the role of athletic activity, specifically gymnastics, on bone mineral density (BMD) accretion, we monitored longitudinal changes in regional and whole body BMD in collegiate women gymnasts and competitive athletes whose skeletons are exposed to differential loading patterns: runners and swimmers. Two cohorts were studied. Cohort I = 26 gymnasts (19.7 ± 1.2 years), 36 runners (21.1 ± 2.7 years) and 14 nonathletic women (19.3 ± 1.7 years) followed over an 8-month period. Cohort II = 8 gymnasts (18.9 ± 1.1 years), 11 swimmers (20.0 ± 2.3 years) and 11 nonathletic women (19.0 ± 1.2 years) followed over a 12-month period. Lumbar spine (L2–4), femoral neck, and whole body BMD (g/cm$^2$) were assessed by dual-energy X-ray absorptiometry. For cohort I, the percent change in lumbar spine BMD after 8 months was significantly greater ($p = 0.0001$) in the gymnasts (2.8 ± 2.4%) than in the runners (−0.2 ± 2.0%) or controls (0.7 ± 1.3%). An increase in femoral neck BMD of 1.6 ± 3.6% in gymnasts was also greater ($p < 0.05$) than runners (−1.2 ± 3.0%) and approached significance compared with controls (−0.9 ± 2.2%, $p = 0.06$). For cohort II, gymnasts gained 2.3 ± 1.6% at the lumbar spine which differed significantly ($p < 0.01$) from changes in swimmers (−0.3 ± 1.5%) and controls (−0.4 ± 1.7%). Similarly, the change at the femoral neck was greater ($p < 0.001$) in gymnasts (5.0 ± 3.4%) than swimmers (−0.6 ± 2.8%) or controls (2.0 ± 2.3%). The percent change in BMD at any site did not differ between eumenorrheic and irregularly menstruating athletes. These results indicate that bone mineral at clinically relevant sites, the lumbar spine and femoral neck, can respond dramatically to mechanical loading characteristic of gymnastics training in college-aged women. This occurred despite high initial BMD values and was independent of reproductive hormone status. The results provide evidence to support the view that high impact loading, rather than selection bias, underlies high BMD values characteristic of women gymnasts. Because all athletes underwent resistance training throughout the year of study, muscle strengthening activity did not appear to be a significant factor in the skeletal response observed in gymnasts. We conclude that activities resulting in high skeletal impacts may be particularly osteotropic for young women. (J Bone Miner Res 1997;12:255–260)**

## INTRODUCTION

Maximizing peak bone mass, as well as reducing its loss before and after menopause, is important for the prevention of osteoporosis. Cross-sectional(1–4) and longitudinal(5) studies report attainment of peak bone mass for the hip and spine, as well as near maximal attainment for other sites and the total body, by late adolescence or early adulthood.(6–8) The increment during adolescence is particularly pronounced in the first few years following menarche in females, and plateaus dramatically after age 16.(2,5) Besides heredity, multiple environmental or lifestyle factors

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contribute to the acquisition of peak bone mass. These include endocrine function, nutritional adequacy, and habitual physical activity.(4,5,9–11)

Since bone mass entering menopause is a determinant for the likelihood of osteoporotic fracture,(5) strategies to maximize bone mineral accretion during adolescence and early adulthood are desired. It is well known that physical activity, a modifiable lifestyle variable, exerts a positive effect on bone mass. The specific characteristics of physical activity that are most important for influencing bone are not completely understood, but it is considered likely that mechanical loads that impart high load magnitudes are more osteotropic than low-intensity loads, and that importance of the number of loading cycles, or repetitions, is relatively modest.(12,13) Numerous cross-sectional(14–18) and prospective(19) studies in athletes and nonathletes indicate that increased mechanical loading through the application of a resistance (such as in weight training) or increased weight-bearing activity (such as running) augments bone mass. However, there are a paucity of longitudinal data in female athletes with varied skeletal loading patterns, especially those with compromised reproductive hormonal status.

One mode of athletic activity, gymnastics training, invokes high impact loading strains on bone which may have powerful osteogenic effects. We have previously reported that regional and total body bone density in competitive collegiate gymnasts exceeds that of runners, swimmers, and nonathletic women, regardless of menstrual cycle status.(20,21) We subsequently monitored changes in bone mineral density (BMD) in these same women to determine whether they are continuing to gain bone despite their high initial values and compromised menstrual function. The results of this investigation forms the basis of the present report.

## MATERIALS AND METHODS

### *Subjects*

One hundred and six young adult women, aged 18–29 years, with varying athletic activity patterns, were observed over an 8- (cohort I) or 12-month (cohort II) period. Cohort I consisted of 26 gymnasts (19.7 ± 1.2 years), 36 runners (21.1 ± 2.7 years), and 14 nonathletic women (19.3 ± 1.7 years). Cohort II included 8 gymnasts (18.9 ± 1.1 years), 11 swimmers (20.0 ± 2.3 years), and 11 nonathletic women (19.0 ± 1.2 years). For cohort I, gymnasts were members of the 1992–1993 and 1993–1994 Oregon State University collegiate team. Runners were competitive middle- and long-distance runners (800 m to marathon) who had trained for their event for at least 1 year prior to enrollment in the study, ran a minimum of 4–5 days/week, and at least 30 mi/week. These athletes were members of the University of Oregon and Willamette University track and cross-country teams and other locally and nationally ranked distance runners living in the mid-Willamette Valley region in Oregon. Athletes in cohort II were members of the Stanford University 1992–1993 and 1993–1994 gymnastics and 1993–1994 and 1994–1995 swim teams. The control groups consisted of college-aged women who exercised no more than 3 h/week and were eumenorrheic (i.e., experienced at least 10 menstrual periods per year). All subjects were in good health, nulliparous, and did not smoke or take any medication except for oral contraceptives that are known to affect bone metabolism. Eleven runners, two swimmers, and two gymnasts from cohort I, but no controls, currently took oral contraceptive medication. The study was approved by the institutional review boards of Oregon State and Stanford Universities, and each subject gave written informed consent.

### *Procedures*

Subjects completed a health, exercise, and menstrual history questionnaire,(22) which included age at menarche, number of menstrual cycles per year (based on age), interruptions in cycles, and oral contraceptive use. Current menstrual status was based on the past year. Menstrual cycle irregularities included amenorrhea (0–3 cycles per year, with none in the previous 6 months) and oligomenorrhea (4–9 cycles per year). A woman was considered eumenorrheic if she reported regular menses (i.e., 10–13 per year).(23) The number of hours spent in athletic training during the previous year was calculated as a weekly average. For the athletes, this included sport-specific training, as well as supplementary training (resistance training and aerobic activity) for approximately 3–5 h/week.

BMD (g/cm$^2$) of the lumbar spine (L2–4), femoral neck, and whole body was assessed by dual-energy X-ray absorptiometry (DXA, Hologic QDR 1000/W, Hologic Inc., Waltham, MA, U.S.A.) at baseline and at 8 (cohort I) or 12 months (cohort II). To adjust for differences in bone size, the bone mineral apparent density (BMAD, g/cm$^3$) was calculated, as previously described.(3,24) In addition, bone-free lean tissue mass (LTM, kg), fat mass (kg), and percent body fat were derived from the whole body scan. Cohort I was assessed at the Bone Research Laboratory (Oregon State University, Corvallis, OR, U.S.A.), while cohort II was assessed at the Musculoskeletal Research Laboratory (Veterans Affairs Medical Center, Palo Alto, CA, U.S.A.). Coefficients of variation in our laboratories for the BMD sites measured are less than 1% and approximately 1.2% for body composition variables. The Hologic QDR-1000/W provides excellent intra- and intersite longitudinal precision.(25) Over the course of the study, the coefficient of variation for the spine phantom was 0.32% at the Musculoskeletal Research Laboratory ($n$ = 507 measurements) and 0.50% at the Bone Research Laboratory ($n$ = 137 measurements).

### *Statistical analysis*

Data were analyzed using the Statview 4.02 statistical software package (Abacus Concepts, Inc., Berkeley, CA, U.S.A.). Analysis included standard descriptive statistics, Student's *t*-tests, and analysis of variance (ANOVA). ANOVA was used to examine differences among groups at baseline and for % change following the observation periods. Where appropriate, the Scheffé test was employed to locate the source of significant differences. An alpha level

Table 1. Baseline Subject Characteristics in the 8-Month Cohort (Mean ± SD)

| | *Group* | | | |
|---|---|---|---|---|
| | *Gymnasts* (n = *26)* | *Runners* (n = *36)* | *Controls* (n = *14)* | |
| Age (years) | 19.7 ± 1.2 | 21.1 ± 2.7 | 19.3 ± 1.7 | R > C* |
| Height (cm) | 158.8 ± 4.7 | 167.8 ± 5.6 | 167.1 ± 8.0 | R,C > G† |
| Weight (kg) | 55.6 ± 6.7 | 54.9 ± 6.5 | 61.0 ± 7.0 | C > G,R‡ |
| Fat mass (kg) | 9.1 ± 2.0 | 8.4 ± 2.6 | 13.6 ± 2.8 | C > G,R† |
| Lean mass (kg) | 44.2 ± 5.0 | 44.4 ± 4.4 | 45.1 ± 4.9 | |
| Body fat (%) | 16.3 ± 2.5 | 15.0 ± 3.3 | 22.2 ± 3.0 | C > G,R† |
| Menarche (years) | 15.9 ± 1.5 | 14.0 ± 1.3 | 13.1 ± 1.3 | G > R,C† |
| Cycles previous year | 7.4 ± 4.9 | 8.2 ± 5.0 | 12.0 ± 0.3 | C > R,G‡ |
| Start training (years) | 8.5 ± 3.9 | 14.1 ± 3.9 | | R > G† |
| Bone mineral density (g/cm$^2$) | | | | |
| lumbar spine | 1.182 ± 0.121 | 0.991 ± 0.110 | 1.114 ± 0.121 | G,C > R† |
| femoral neck | 1.104 ± 0.090 | 0.917 ± 0.108 | 0.971 ± 0.115 | G,C > R† |
| whole body | 1.111 ± 0.068 | 1.060 ± 0.070 | 1.096 ± 0.067 | G > R* |

*$p < 0.05$, †$p = 0.0001$, ‡$p < 0.01$.

Table 2. Baseline Subject Characteristics in the 12-Month Cohort (Mean ± SD)

| | *Group* | | | |
|---|---|---|---|---|
| | *Gymnasts* (n = *8)* | *Swimmers* (n = *11)* | *Controls* (n = *11)* | |
| Age (years) | 18.9 ± 1.1 | 19.0 ± 1.2 | 20.0 ± 2.0 | |
| Height (cm) | 158.7 ± 4.4 | 174.1 ± 5.3 | 166.7 ± 5.1 | S > C > G* |
| Weight (kg) | 55.9 ± 5.8 | 66.5 ± 6.5 | 60.3 ± 5.4 | S > G† |
| Fat mass (kg) | 9.5 ± 1.6 | 12.1 ± 2.6 | 14.5 ± 2.2 | C > S,G‡ |
| Lean mass (kg) | 44.1 ± 4.6 | 52.1 ± 4.7 | 43.6 ± 4.5 | S > G,C‡ |
| Body fat (%) | 17.1 ± 2.4 | 18.0 ± 2.8 | 24.1 ± 2.9 | C > G,S* |
| Menarche (years) | 16.4 ± 1.7 | 13.3 ± 1.3 | 12.8 ± 1.5 | G > S,C* |
| Cycles previous year | 6.4 ± 4.4 | 10.8 ± 2.1 | 11.9 ± 0.3 | S,C > G‡ |
| Start training (years) | 10.5 ± 2.9 | 7.0 ± 3.5 | | G > S* |
| Bone mineral density (g/cm$^2$) | | | | |
| lumbar spine | 1.139 ± 0.135 | 1.111 ± 0.104 | 1.093 ± 0.132 | |
| femoral neck | 1.043 ± 0.153 | 0.882 ± 0.109 | 0.871 ± 0.148 | G > S,C§ |
| whole body | 1.107 ± 0.109 | 1.069 ± 0.050 | 1.070 ± 0.096 | |

*$p = 0.0001$, †$p < 0.01$, ‡$p < 0.001$, §$p < 0.05$.

of 0.05 was required for significance. Results are given as mean ± SD unless stated otherwise.

## RESULTS

### *General*

Group characteristics for both cohorts are presented in Tables 1 and 2. Similar data for most of these women have been reported previously(20,21); however, several women have been added to the various study groups. Therefore, baseline data on the expanded population are shown. There was no difference in any measured variable between those athletes taking oral contraceptives and those who were not; therefore, results for individual athlete groups were combined. Gymnasts from both cohorts exhibited similar age and body composition characteristics and had a later age of menarche than the other athletes and controls. For both cohorts, athletes had a lower absolute and relative fat mass than nonathletic women. There was no difference among groups for lean mass in cohort I; however, for cohort II, swimmers, who were taller and heavier than gymnasts, had a greater lean mass than either gymnasts or controls. This difference disappeared when lean mass was normalized for body weight. For both cohorts, only trivial changes in body composition occurred during the study period.

Both gymnasts and swimmers commenced sport-specific training prior to menarche, with runners beginning training during midadolescence. During the period of observation, gymnasts and swimmers trained for approximately 20 h/week. These athletes trained year-round, and underwent approximately 3 h/week of weight training and 2.5 h/week of aerobic activity (running, cycling). Runners averaged 43.1 ± 15.6 mi/week and included a similar amount of weight training in their exercise regimen as the gymnasts and swimmers.

At the commencement of the study, 28% of the runners reported menstrual cycle irregularity: 5 were amenorrheic and 5 oligomenorrheic; the remaining 26 runners were eumenorrheic. Thirty-one percent of the Oregon State gymnasts reported menstrual cycle dysfunction: two were amenorrheic and six oligomenorrheic, while for the Stanford gymnasts, 3 were amenorrheic and 1 was oligomenorrheic. However, only one of the Stanford gymnasts remained amenorrheic for the full year of study, the other two becoming oligomenorrheic and eumenorrheic, while the oligomenorrheic athlete became eumenorrheic. Three swimmers were oligomenorrheic at the beginning of the study. During the year of observation, one of the oligomenorrheic swimmers became eumenorrheic, and one eumenorrheic athlete became oligomenorrheic. There was no change in menstrual status for the runners or gymnasts in the 8-month cohort. All the control subjects remained eumenorrheic during the study period.

### *Baseline BMD*

BMD results at any site did not differ ($p > 0.05$) when subjects were stratified by menstrual status; therefore, no distinction by menstrual status is made. For cohort I, differences among groups existed at each site (Table 1); the gymnasts consistently displayed the highest and runners the lowest BMD. These differences among groups existed when BMD was adjusted for differences in bone size (BMAD) and body weight.

For cohort II (Table 2), femoral neck BMD of gymnasts was higher than swimmers and nonathletic women, with no significant differences among groups at the lumbar spine or for the whole body. When adjusted for body weight, gymnasts' BMD was greater ($p < 0.01$) than swimmers at all sites and greater than controls at the femoral neck and the whole body. When adjusted for bone size, there was no difference among groups at the lumbar spine, but the femoral neck BMAD of gymnasts was greater than swimmers and controls, while whole body BMAD of gymnasts exceeded that of the swimmers.

### *Changes in BMD*

Bone density changes did not differ by menstrual status or oral contraceptive use. Therefore, the BMD results within each group were pooled.

Gymnasts in both cohorts gained significantly greater bone than the other athletes and controls (Fig. 1). The 2.8 ± 2.4% increase in lumbar spine BMD for the cohort I gymnasts was similar to the 2.3 ± 1.6% change experienced by those in cohort II, and both changes differed from zero ($p < 0.01$). Nonsignificant changes for the runners and controls and swimmers and controls were not different from one another and were not significantly different when compared with zero (i.e., no difference).

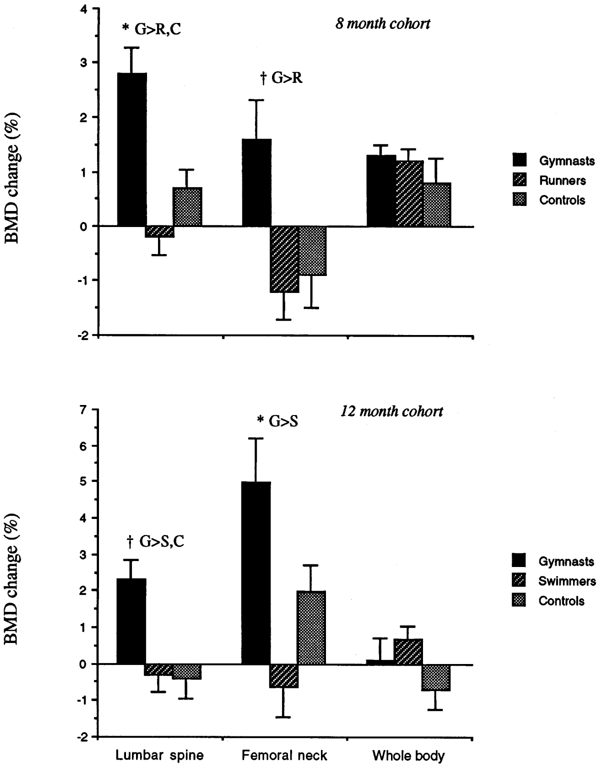

**FIG. 1.** Percent change in lumbar spine, femoral neck, and whole body BMD for 8-month (top panel) and 12-month (bottom panel) cohorts. $^{*}p < 0.001$, $^{\dagger}p < 0.01$. Values are mean ± SEM.

Gymnasts from both cohorts experienced gains in femoral neck BMD compared with runners and swimmers, respectively, but did not differ from their control groups. When compared with zero, both the runners and 8-month gymnasts changes were significant ($p < 0.05$) (i.e., a loss for the runners and a gain for the gymnasts). For the 12-month cohort, the change in gymnasts BMD (5.0 ± 3.4%) was significantly different from zero ($p < 0.01$) as was the 2.0 ± 2.3% BMD gain in the controls ($p < 0.05$). There were no differences among groups in either cohort for change in whole body BMD; however, both the 8-month gymnasts' and runners' gains were significant when compared to zero.

## DISCUSSION

These results demonstrate striking increases in bone density at clinically relevant sites subsequent to long-term gymnastics training in college-aged women. This result occurred despite high initial BMD values and was independent of reproductive hormone status. This finding provides evidence to support the view that high-impact loading, characteristic of gymnastics training, rather than selection bias, underlies high BMD values observed in female gymnasts.

Our findings are in accordance with those of Nichols et al.,(26) who monitored gymnasts and controls for 6 months and observed a 1.3% increase in the lumbar spine BMD of gymnasts with no change in the controls. By contrast, Nichols et al.(26) found only a nonsignificant 1.4% trend toward increased femoral neck BMD, which probably reflected a small sample size and brief duration of follow-up. No change was observed in whole body BMD.

Because athletes frequently engage in resistance training, which itself can lead to modest bone mineral accretion in college-aged women,(19) it is unknown how much of the gains observed by Nichols et al.(26) may be due to weight training rather than the high impacts incurred through bounding, jumping, tumbling, and vertical landings that characterize gymnastics training. In the present study, both swimmers and runners underwent resistance training on a regular basis throughout the year, in a similar fashion to the gymnasts. Thus, weight training undertaken by the gymnasts does not appear to be the critical factor. Further, the duration of the study, 8 and 12 months, provided sufficient time for alterations in bone mineral to be observed.

Both groups of gymnasts in the present study displayed similar increases at the lumbar spine of approximately 2.5%. This is not surprising because they are both nationally ranked teams, with similar age, body habitus, menarcheal age, and training regimens. It is possible that the more recent onset of menarche in the gymnasts contributed to the observed BMD gains. Gymnasts attained menarche at approximately 16 years, and because the influence of sex steroids is pronounced in the first few years of the adolescent growth spurt,(2,5) an additive effect with exercise may have occurred. Although both teams experienced significant increases at the femoral neck, the gains made by cohort II gymnasts were quite dramatic. Both baseline assessments for these women were made prior to commencing the competitive season, with cohort I gymnasts reassessed upon completion of competition and cohort II prior to the beginning of the following competitive season. Therefore, it is unlikely that the timing of measurements accounts for the apparent intergroup difference because both team's post tests were undertaken while in full training or competitive condition. The longer period of observation for cohort II gymnasts may partially account for their notable femoral neck gains. In addition, although a reasonable level of physical training was maintained during the summer period for cohort II (~15 h/week), time devoted specifically to gymnastics training was reduced. It is conceivable that enhanced bone mass gains occurred during the fall training period because the hip was more responsive to impact forces and varied strain rates with resumption of regular gymnastics training. Indeed, Rubin and Lanyon(27) have proposed that a diverse exercise regimen may provide a greater osteotrophic effect than a monotonic program. In contrast, little change in bone mass was observed in the runners, swimmers, or controls. For both runners and swimmers, changes at these regional sites were in the negative direction. This occurred despite high volumes of training.

We(20,21) and others(17,18) have previously discussed the high impact forces and strain rates incurred by athletes as potential mechanisms for enhanced bone mineral. Specifically, for runners, forces on the lower limbs can be 2–5 times body weight,(28) while those at the lumbar spine are 1.75 times body weight.(29) In contrast, forces at the hip in gymnastics are as high as 10–12 times body weight,(30) and high strain rates result from rapid acceleration and deceleration movements. The beneficial effect of impact forces has also recently been shown in a prospective study of nonathletic premenopausal women where hip bone density gains of 3–4% were observed following 6 months of intermittent jumping exercise.(31) The mechanical loading of swimming, resulting from muscle pull via tendon attachments to insertion sites, appears ineffective at the regions measured in this study to alter bone mineral.

Diet, specifically calcium intake, may influence bone changes in association with exercise,(32–34) although a recent cross-sectional study by Henderson et al.(35) suggests that bone density in young women is not associated with dietary intakes. We have previously reported(20) similar macronutrient, calcium, and phosphorus intakes in a subgroup of these gymnasts and runners. Diet assessment of cohort II was obtained by a food frequency questionnaire(36) for the observation period. Although an intergroup difference was found for calcium intake (ANOVA, $p < 0.05$), with both gymnasts and controls consuming less than the Recommended Dietary Allowance of 1200 mg/day, it was not significantly large to be detected by the Scheffé post hoc test. Moreover, there was no difference for body weight adjusted energy, protein, or carbohydrate intake, although fat intake was less in gymnasts than swimmers and controls. Therefore, it appears unlikely that differences in nutrient intake contributed to the observed results.

The ability to increase bone mass significantly during the third decade of life offers the prospect of a greater safety margin against age-related bone loss and skeletal fragility later in life. Recker et al.(8) have shown that habitual physical activity is an independent predictor of bone acquisition for women in the third decade. The results of this study extend this finding by indicating that activities resulting in high impacts to the skeleton may be particularly osteotropic.

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