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**Original Article**

# Effect of different collegiate sports on cortical bone in the tibia

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**Abstract**

**Objectives:** The purpose of this study was to determine the effect of sports participation on cortical bone in the tibia. **Methods:** 53 female collegiate athletes (25 cross-country, 16 soccer, and 12 volleyball) and 20 inactive controls had the left distal 20% tibia scanned by pQCT. Cortical volumetric BMD (vBMD) was measured within the cortical shell at the anterior, posterior, medial, and lateral regions and standard deviations were calculated. **Results:** Total vBMD was greater in the control group (1161±5 mg/mm$^3$) than each of the sports ($p<0.05$). Soccer players (1147±5 mg/mm$^3$) had greater vBMD than volleyball players (1136±7 mg/mm$^3$) ($p<0.05$), but similar to cross-country runners (1145±5 mg/mm$^3$). Cortical thickness was greatest in soccer players (4.1±0.1 mm), while cross-country and control subjects (3.8±0.1 mm) had greater thickness than volleyball players (3.4±0.1 mm)($p<0.05$). Periosteal circumference was greater in volleyball players (71±1.4 mm) than soccer, cross-country, and control subjects (68±0.9, 69±0.8, and 66±1 mm, respectively; all, $p<0.05$). vBMD variation within the cortical shell was greater among control subjects (70±6 mg/cm$^3$) than each of the athlete groups, with soccer players having lower variation than cross country runners (within-in person SD 36±6 mg/cm$^3$ and 54±5 mg/cm$^3$ respectively; $p<0.05$). **Conclusion:** These results indicate bone geometry and distribution within the cortical shell of the tibia varies depending upon sporting activities of young women.

**Keywords:** Bone, Athletes, Female, Stress-fracture, pQCT

## Introduction

Bone size, volumetric bone mineral density (vBMD) and cortical thickness influence bone strength. Physical activity is widely accepted as a method for improving bone health. Wolff's law states that bone structure is altered based on the loads that are placed on it[1]. This effect is accomplished through modeling and remodeling, resulting in increased bone strength to accommodate increased loads and bone loss in response to decreased loads. Frost's theory of the "mechanostat" follows the idea that bone adaptations occur based on the magnitude of the load that is placed up on it with different magnitudes of loading causing bone loss, maintenance and bone gain[2-5].

The authors have no conflict of interest.

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In some studies that have used DXA, areal bone mineral density (aBMD) has been reported to be increased at certain sites throughout the body in individuals participating in high-impact loading sports[6-10]. However, a study that used pQCT reported that vBMD at the tibia in non-athletes was higher than athletes[11]. While many studies have reported improvement in hip and spine areal BMD (aBMD) with physical activity, this effect may be site specific[11], and bone size and shape also may be affected. An increase in hip cross-sectional area in volleyball, hurdling, squash, soccer, speed-skating, step-aerobic instructing, weight-lifting, orienteering, and cross-country skiing compared to a group of non-athletic controls has been reported[9]. Furthermore, an increase in the strength of weight-bearing bones compared to controls has also been reported along with site-specific bone thickening; however no load-specific differences were observed[10]. Increased loading has been reported to increase bone size in athletes[12-14] and post-menopausal women[15]. This is important because bone size contributes significantly to bone strength, and has been reported to be decreased in individuals with a history of stress-fracture[16,17]. Increased knowledge regarding specific adaptations of bone in response to different loading types may aid sports medicine

| Sport | Age (years) | Height (cm) | Weight (kg) | Body Fat (%) | Menarcheal Age |
|---|---|---|---|---|---|
| Control (n=20) | 19.2±1.4 | 165.6±5.4$^{A}$ | 64±13 | 30±6.0$^{A}$ | 13.7±1.0 |
| Soccer (n=16) | 19.2±1.0 | 166.1±5.7$^{A}$ | 65±10 | 23±5.7 | 13.2±0.9 |
| Volleyball (n=12) | 18.6±0.8 | 177.0±7.5$^{ABC}$ | 73±7$^{A}$ | 23±3.7 | 13.1±1.5 |
| Cross-Country (n=25) | 19.8±1.5 | 166.9±6.5$^{C}$ | 59±7$^{A}$ | 19±3.5$^{A}$ | 14.3±1.4* |

** 2 subjects had never menstruated and were not included in the analysis.*
*Values are means ± SD and means with the same letters within a column are significant at p<0.05.*

**Table 1.** Descriptive characteristics of the different groups.

professionals in the prevention of stress fractures through exercise protocols designed to strengthen bone. In addition, improved knowledge regarding these adaptations in bones of athletes may improve the overall understanding of why some athletes are more susceptible to stress fractures.

The purpose of this study was to investigate the effect of participation in different collegiate sports on bone mass and geometry of the tibia. We hypothesized that athletes participating in volleyball would have the largest and strongest bone independent of bone density because of the high impact forces placed on the tibia during jumping. Our hypothesis is supported by previous pQCT studies which have reported an increase in bone size as a result of participation in high-impact or odd-impact activities[10,11,18].

## Materials and Methods

Subjects included fifty-three female NCAA division 1 college athletes (25 cross-country, 16 soccer and 12 volleyball) recruited from teams on our campus and 20 inactive controls were enrolled in the study. Controls were only allowed to participate if they participated in physical activity 2 or less times per week for a total of less than 60 minutes.

Height was measured to the nearest 0.5 cm using a portable stadiometer (Seca Model 225) and weight was measured to the nearest 0.1 kg using a digital scale (Seca Model 770). Body fat percentage was obtained by total body dual x-ray absorptiometry (DXA; Hologic Apex Version 3.2). All participants completed a questionnaire to obtain information about menstrual status, family history of osteoporosis, medications, supplements, sleeping habits, and activities of daily living. Participants also kept a 72-hour diet recall to determine vitamin D, calcium, and macronutrient intakes. Diets were analyzed using The Food Processor Software (ESHA Research Version 10.2).

The sport groups used in this study were selected to represent generalized patterns of loading which would be expected in athletes participating in these sports. Volleyball was selected to represent a sport in which jumping was a major component of the loading pattern. Soccer was used to represent a loading pattern which consists of many changes of direction and short bursts of acceleration. Cross-country was selected to represent a unidirectional, low-impact repetitive loading pattern. Coaches from each of the teams were interviewed to obtain information regarding practice schedules both in and out of season. Information regarding weight training and plyometric training were obtained from members of the strength and conditioning staff.

Bone images were obtained at 20% of the tibia length from the distal end using the XCT 3000 (Orthometrix, Inc.). Voxel size was set to 0.5 mm at a speed of 20 mm/second. Tibia length was measured using a segmometer (Rosscraft) as the total distance between the medial condyle and the medial malleolus of the tibia. Slice images were analyzed using contour mode 2, peel mode 2, and threshold of 400 mg/cm$^3$ for total bone area; separation mode 1 and threshold 710 mg/cm$^3$ for cortical bone outcomes. Additionally, regions of interest (ROI) were placed using a crosshair method at the anterior, posterior, medial, and lateral points of the cortical shell. The ROIs were 4-by-4 voxels in size and placed in the center of the cortical shell which prevented any partial volume effects from affecting the results.

Our institution's Human Subjects Review Committee approved the protocol and informed consent was obtained from all participants prior to testing.

### *Statistical Analysis*

All analyses were performed using Stata Release 11 (StataCorp LP). The relationships between cortical vBMD, cortical thickness, periosteal circumference, polar strength strain index (pSSI) and the standard deviation (SD), or variation, of vBMD within the cortical shell were analyzed using ordinary least squares regression. All dependent variables were modeled using height, lean mass, fat mass, family history of osteoporosis (yes/no), menstrual status, sport, age, vitamin D intake, calcium intake, macronutrient intakes (fat, protein & carbohydrate), and history of stress fracture (yes/no) as covariates. Only variables which remained significant at p<0.05 were included in the models. Cortical vBMD SD among the four ROIs was calculated for each individual. A repeated measures analysis of variance with height, lean mass, fat mass, sport, ROI, and sport-by-ROI interaction with subject nested within sport was used to analyze differences in vBMD by ROI, as well as vBMD SD. Results are reported as least square means ± standard error of the mean. Post-hoc comparisons of least square means were performed using Tukey's HSD.

| Sport | In-season practice | Off-season practice | In-season competition | In-season lifting | Off-season lifting |
|---|---|---|---|---|---|
| Cross-country | 60 to 90 minutes of running per day 6 d/wk | 60 to 90 minutes of running per day 6 d/wk | 1 race of 5 kilometers per week | None | None |
| Soccer | 60 minutes of training per day 4 d/wk | 60 minutes of training per day 4 to 5 d/wk | 2 matches per week | 1 day per week | 3 days per week* |
| Volleyball | 120 to 150 minutes of practice per day 4 d/wk | 60 minutes per day 2 d/wk | 2 matches per week | 2 days per weedk | 3 days per week* |
| Control | None | None | | None | None |

** Soccer and Volleyball athletes participate in 30 minutes of plyometric training once per week in the off-season.*

**Table 2.** Description of training and competition history of the different groups.

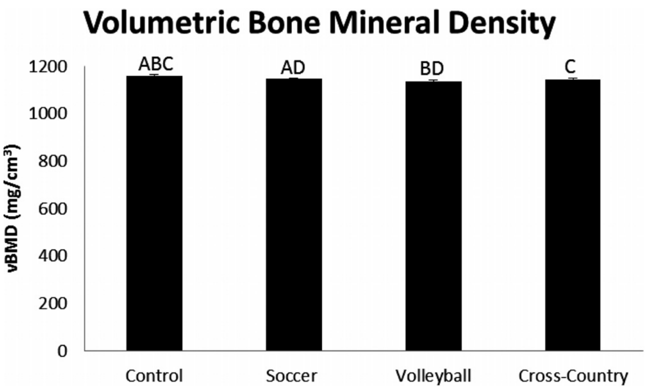


**Figure 1.** Cortical vBMD of the tibia among the controls and athletic groups was greater in controls compared to all athletic groups and higher in soccer players than volleyball players. Data are least square means ± SE after controlling for height, lean mass, and fat mass. Means with the same letters are significantly different at p<0.05.

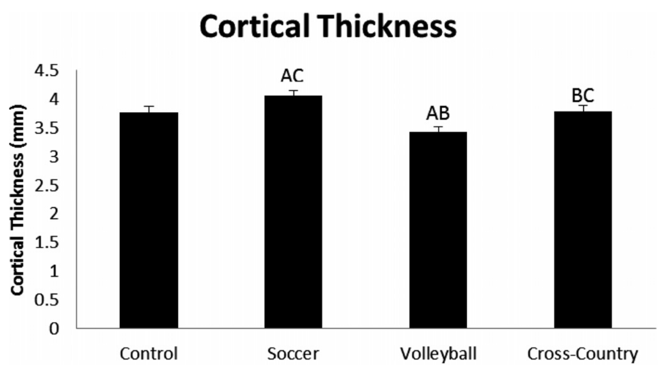


**Figure 2.** Cortical thickness of the tibia among the different athletic groups. Data are least square means ± SE after controlling for height, lean mass, and fat mass. Means with the same letters are significantly different at p<0.05.

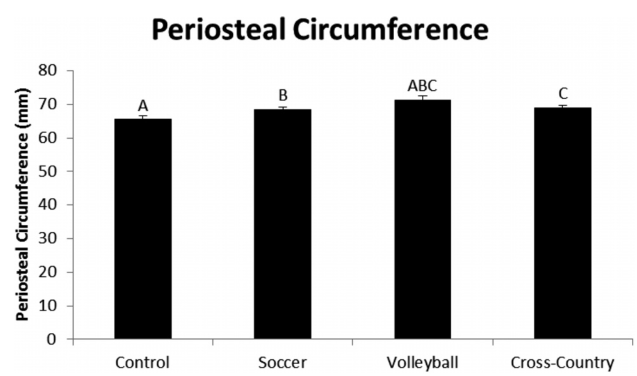


**Figure 3.** Periosteal circumference of the tibia among the different athletic groups. Data are least square means ± SE after controlling for height, lean mass, and fat mass. Means with the same letters are significantly different at p<0.05.

## Results

Subject characteristics are given Table 1. Volleyball players were taller than each of the groups and heavier than cross-country runners, while cross-country runners had less body fat than the control group. All groups were of similar age and had similar menarcheal age; however, two cross-country athletes had never menstruated and were omitted from the analysis. Control subjects were asked questions regarding physical activity and were classified as inactive. Training information for each of the sports is given in Table 2.

Cortical vBMD and cortical shell thickness are shown in Figures 1 and 2. Cortical vBMD was greater in control subjects than any of the athlete groups ($p<0.05$). Soccer players had greater cortical vBMD than volleyball players, but cross-country runners were not different from soccer or volleyball. Cortical thickness was greater in soccer players than volleyball players and cross-country runners, while the control group was intermediate and did not differ from any of the other groups. After controlling for height, lean mass, and fat mass, periosteal circumference was greater in volleyball players than all of the other groups (Figure 3). A negative relationship existed between periosteal circumference and vBMD with periosteal circumference explaining 21 percent of the variability in vBMD. A similar rela-

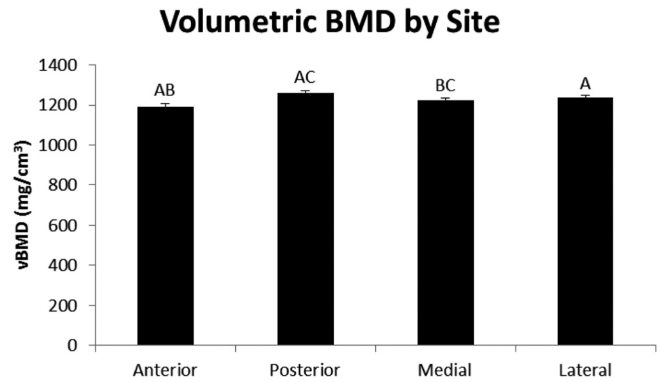


**Figure 4.** Cortical vBMD at the anterior, posterior, medial and lateral sides of the tibia. Data are least square means after controlling for height, lean mass and fat mass, and taking into account the repeated measures within an individual. Means with the same letters are significantly different at p<0.05.

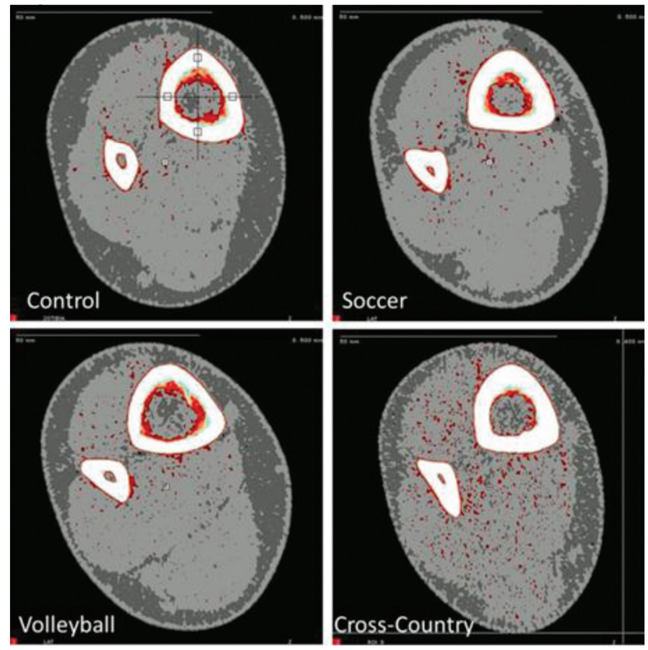


**Figure 5.** Representative pQCT images from each athletic group illustrate the differences that were observed.

tionship existed between polar strength strain index (pSSI) and vBMD with no differences existing between sports: Mean pSSI (±SD) for volleyball players, control subjects, cross-country runners, and soccer players was 1554±163 mm$^3$, 1249±263 mm$^3$, 1309±213 mm$^3$, and 1360±156 mm$^3$ respectively.

Mean cortical vBMD within the different ROIs are shown for each athlete group in Figure 4. vBMD at the anterior site was lower than all other sites. vBMD at the posterior site was the greatest, while the lateral and medial vBMD were intermediate. The variability in vBMD within the cortical shell (vBMD SD) was greater among control subjects (70±6 mg/cm$^3$) than all the athletic groups ($p<0.05$). Cross-country runners (54±5 mg/cm$^3$) had greater vBMD SD than soccer players (36±6 mg/cm$^3$, $p<0.05$), but neither sport differed significantly from volleyball players (45±8 mg/cm$^3$). The differences in vBMD observed among the different regions were similar among the four groups (tested as region by group interaction). Variability of vBMD within the cortical shell was significantly related ($p<0.001$) to total vBMD in the tibia, with greater variability associated with lower vBMD (Figure 6). The relationship between cortical shell variability and cortical vBMD remained significant ($p=0.006$) when the control subjects were excluded from the analysis.

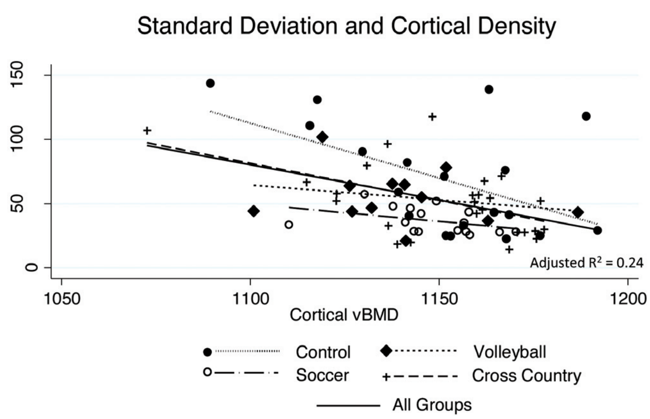


**Figure 6.** Relationship between the standard deviation of the four regions of interest and the cortical vBMD. The overall relationship between the SD for the four regions and cortical vBMD was significant at $p<0.001$. The relationship between SD and cortical vBMD was similar among groups (tested as vBMD-by-group interaction).

## Discussion

Our results show a higher vBMD among control subjects than any of the athletic groups, which is consistent with a previous study that have reported greater vBMD at the tibia in control subjects[11]. This is contrary to some earlier studies which have reported increased aBMD at different locations throughout the lower extremity in different athletic groups than the control groups in each of the studies[6,7,19-21]. One reason for this may be due to a decrease in the amount of remodeling occurring in the control subjects because of their sedentary lifestyle. While many studies have utilized DXA, one study used pQCT to investigate cortical vBMD differences in the tibia of national level volleyball players, hurdlers, racket game players, soccer players and swimmers and also found no significant differences among groups[18]. Participation in collegiate athletics should promote increased remodeling because of the loads being placed on the tibia. Since newly remodeled bone is less dense than older bone tissue[22], it would be logical that the control subjects would have the highest vBMD. However, volleyball players had the greatest periosteal circumference and the lowest vBMD. One reason why this relationship may exist is because the volleyball players are remodeling more frequently due to the impact loading from jumping and gain bone at the periosteum. Interestingly, the increase in bone size is not accompanied by an increase in thickness which may indicate a large degree of specificity of adaptations to physical loading types. Volleyball players were taller and heaver, but even after controlling for these covariates, they were still found to have a greater periosteal circumference than the other athletes. In our study, greater periosteal circumference was related to a lower vBMD which may be due to increased remodeling as a result of periosteal expansion.

Soccer players had a greater mean cortical thickness than volleyball and cross-country athletes, but did not differ from the control group. The differences in cortical thickness may be attributable to differences in the loading patterns among sports. To our knowledge, the precise loading patterns of soccer, volleyball, and cross-country have not been compared. In a similar study, volleyball and soccer were classified as high-impact and odd-impact respectively in an effort to find associations between loading patterns and bone geometry[18]. These investigators found that cortical wall thickness did not differ significantly between soccer and volleyball players, but cortical thickness was greater in hurdlers and soccer players than swimmers, who represented a low-impact repetitive group. Figure 5 is a representative image from a subject within each of the 4 groups. As noted in the Results, soccer players had greater cortical thickness than volleyball players or cross-country runners and volleyball players had a greater periosteal circumference with a thin cortex. While soccer players had thicker bones, this did not predict greater bone strength due to the large influence of bone size on pSSI.

We reported the cortical vBMD of the anterior region to be 3 to 5 percent less than the other ROIs. These differences are smaller, but similar to previous work that reported differences of 6 to 12 percent between the anterior and posterior regions of interest[23,24]. In our study, cortical vBMD also was lower at the medial ROI than the posterior ROI. Many stress fractures occur in the anterior-medial aspect of the tibia[25,26] and these findings offer a possible explanation of why this may occur. An important finding of this study is the significant relationship between the variability among the four ROIs and the overall vBMD of the cortical shell. Individuals with greater vBMD variability had lower overall cortical vBMD which may indicate that increased remodeling is occurring in these individuals. The mechanism behind this relationship is unclear, and requires further study.

There are several limitations to this study. One limitation is the dynamic nature of sport participation. Each individual within a given sport may have a loading pattern that could differ from the normal expected loading pattern. Another limitation is the absence of information regarding the number of years each athlete had participated in their sport. We did not find, however, a relationship between the bone measures and the number of years of participation at the collegiate level, although there was not a large range in years of participation. Finally, not all of the athletes in each of the groups participated in the study which may affect the representativeness of the sample.

The results of this study indicate that bone geometry and distribution of mass within the cortical shell of the tibia varies depending upon sport participation. Our results indicate that sports requiring dynamic movements, such as soccer, may develop bones with greater cortical thickness with less variability in vBMD throughout the cortical shell. The observation that inactive controls had the greatest vBMD suggest that at the tibia a reduction in exercise-induced remodeling may result in greater vBMD. Additionally, individuals with greater variability in vBMD throughout the cortical shell have a lower mean vBMD. We speculate that the greater periosteal circumference and decreased cortical vBMD that is observed in the volleyball players is a result of increased periosteal expansion and increased remodeling. Increased remodeling would theoretically lead to increased cortical porosity and a lower cortical vBMD." One intriguing finding of this study is the disconnect between periosteal circumference and cortical thickness. Biomechanical testing may be necessary to determine the precise forces being exerted on bones during volleyball. Future research should focus on bone changes during a competitive season, as well as investigation into the mechanism behind the variability and vBMD relationship.

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