

Changes of Lower Limb Bone Mineral Density in Division I Female Athletes During an Athletic Season

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Introduction: Bone mineral density (BMD) from dual-energy x-ray absorptiometry (DXA) provides bone health information. BMD monitoring in collegiate athletes may be beneficial for performance and overall bone health. Currently, there is limited information regarding BMD among female Division I athletes, with no studies tracking pre- to postseason dominant and non-dominant limb BMD in this demographic. The purpose of this study was to assess changes in lower limb BMD in this population from pre- to postseason.

Methods: Sixty-four participants (field hockey, soccer, and volleyball) were included in this analysis. Preseason DXA scans were completed before the start of the athletic season and postseason was on average collected 126.5 ± 13.4 days after. A full-body DXA scan was completed, and dominant and non-dominant lower limb BMD values were utilized in the statistical analysis. A 2×2 ANCOVA was conducted with sport type set as a covariate.

Results: Preseason (age: 20.4±1.56 years, height: 168.0±7.2 cm, weight: 66.0±9.4 kg) lower limb BMD was not significantly different from postseason. The interaction between time and limb ($F_{1,61}=0.09$, $p=0.76$) was not significant. No significant main effects were seen for time ($F_{1,61}=0.80$, $p=0.38$). There was a significant main effect for limb ($F_{1,61}=4.45$, $p=0.04$).

Conclusion: No significant changes were seen in lower limb BMD from pre- to postseason in female athletes, a significant difference was observed between the dominant and non-dominant limb. BMD monitoring is important to preserve bone health and future research should explore BMD changes over multiple seasons to assess potential sport-specific or cumulative effects.

Plain Language Summary: Bone mineral density remains constant from pre- to postseason in Division I female athletes, however, athletes did have a significant difference between their dominant and non-dominant limb bone mineral density. Therefore, bone health remains stable during an athletic season in Division I female athletes.

Keywords: pre-season, skeletal health, lower limb, dual-energy X-ray absorptiometry

Introduction

Bone mineral density (BMD), measured using dual-energy X-ray absorptiometry (DXA), is a key indicator of bone health and potential fracture risk across various populations.¹ A decline in BMD increases susceptibility to fractures, making DXA a widely used, safe, and reliable tool for monitoring bone density over time.² While BMD is often discussed in the context of aging and osteoporosis, maintaining optimal bone health is equally important in younger individuals, as peak bone mass attained in early adulthood and adolescence is a key determinant of lifelong skeletal integrity.^{3–5} Furthermore, athletes with lower BMD are at a higher risk of experiencing fractures which could ultimately hinder individuals athletic career.⁶ Bone health in female athletes is important to monitor as they are more susceptible to stress fractures compared to males,^{7–9} Tracking BMD fluctuations can provide insight into potential risk factors, such as energy deficits, inadequate nutrition, or high-impact training loads.^{10,11}

Collegiate athletes are routinely exposed to intense training regimens, often involving repetitive loading, high-impact activities, and competition stressors that may influence BMD.¹² DXA can be used to monitor for early indicators of the female athlete triad and osteoporosis, both of which are associated with low bone mineral density and females are a high risk of development.^{13,14} In a mixed cohort study of basketball, soccer, and hockey collegiate athletes during their first two years of training, there was a 0.05 g/cm² increase in lower limb BMD within the first year.¹⁵ These findings support the relationship between activity and BMD, and that BMD changes can be detected over a short period (1 year). However, few studies have assessed changes within a single competitive season (pre- to postseason) and between limbs (dominant vs non-dominant), particularly in female athletes varying across multiple sports.^{15,16}

Therefore, the purpose of this study was to assess lower limb BMD changes between dominant and non-dominant limbs in Division I female athletes from preseason to postseason across multiple sports. We hypothesized that there may be moderate change in lower limb BMD when observed from pre- to postseason. Understanding whether BMD remains stable or fluctuates during a competitive season will inform strategies for optimizing training regimens, monitoring athlete health, and reducing the risk of bone-related injuries in collegiate sports.

Methods

Study Design

This study examined lower limb BMD changes in Division I female collegiate athletes from preseason to postseason in field hockey, soccer, and volleyball. These sports were selected to represent a range of mechanical loading patterns, with soccer and field hockey emphasizing lower-limb activity, and volleyball involving frequent jumping and landing that also place substantial loads on the lower extremities despite greater upper-limb use. Preseason assessments were conducted prior to the start of each team's (field hockey, soccer, and volleyball) athletic season, while postseason testing was completed at the earliest available opportunity following the conclusion of competition (126.5 ± 13.4 days between DXA scans). On average there were 17 days between testing and the start of the athletic season, and post-testing was completed on average 22 days following the completion of the athletic season. This study complies with the Declaration of Helsinki.

Participants

Participants in this study were female Division I collegiate athletes that were recruited from the university's soccer, field hockey, and volleyball teams, and were competing at both timepoints. Inclusion and exclusion criteria can be found in Table 1.

DXA Scan

Whole-body DXA scans were conducted using the Hologic DXA (Horizon Bone Densitometry System, Hologic Inc., Bedford, MA; Software Version: 5.6.1.3 rev 007) system to assess BMD. The DXA system was calibrated at the start of each testing session using a standard phantom to ensure measurement accuracy. During the scan, participants were instructed to wear lightweight clothing, remove any metal objects, and lie supine on the scanning table. Arms were positioned at their sides, and limbs were kept straight with feet in 10–20° of dorsiflexion. The scan proceeded from the

Table 1 Inclusion and Exclusion Criteria

Inclusion	Exclusion
Active members of their respective team (soccer, field hockey, basketball). Regularly participating in practices, games, and training sessions at the time of data collection. Female. Between the ages of 18 and 24.	Significant musculoskeletal injuries in the previous four months and/or any contraindications to completing a DXA based on the manufacturers recommendations. Athletes who experienced significant time loss due to other outstanding factors. Concussions or illness. Chronic musculoskeletal or metabolic bone conditions. Osteoporosis or osteopenia. Athletes who had used medications known to influence bone health. Corticosteroids or hormone replacement therapy

full length of the body, and participants were required to remain still for the duration of the scan. The DXA whole body scans were analyzed following the manufacturers' guidelines, which have been previously published.¹⁷ The lower limbs were segmented through the femoral neck and included the participants metatarsals, to encapsulate the entirety of both limbs. From the whole body scans the dominant and non-dominant lower limb BMD values were extracted for each participant and utilized within the statistical analysis.

Statistical Analysis

Statistical analyses were conducted using SPSS (Version: 28.0.1.1) for Windows.¹⁸ A dependent *t*-test was used to assess changes in demographic characteristics between the two timepoints. A 2×2 ANCOVA, with sport type included as a covariate, was performed to evaluate the effects of time (preseason vs postseason) and limb (dominant vs nondominant) on BMD. Both time and limb were treated as main effects, and their interaction was also analyzed to determine whether BMD changes varied between limbs across the season. The level of significance was set to $p < 0.05$.

Results

A total of 64 Division I female athletes were assessed for lower limb BMD at both preseason and post-season and demographic characteristics are presented in Table 2. A post-hoc power analysis conducted in G*Power (version 3.1) for the repeated measures 2×2 ANOVA (effect size $f = 0.27$, $\alpha = 0.05$, $N = 64$) indicated a statistical power of 0.84 to detect differences between limbs across time points. The interaction between time and limb was not significant ($F_{1,61} = 0.09$, $p = 0.76$), suggesting that seasonal changes in BMD did not differ between the dominant and nondominant lower limb BMD (Figure 1). No significant main effect was observed for time ($F_{1,61} = 0.80$, $p = 0.38$). Estimated marginal means were 1.24 g/cm² (95% CI [1.22, 1.27]) for preseason and 1.25 g/cm² (95% CI [1.23, 1.27]) for post season. There was a significant main effect seen with limb ($F_{1,61} = 4.45$, $p = 0.04$). Estimated marginal means were 1.215 g/cm² (95% CI [0.19, 1.24]) for the non-dominant limb and 1.217 g/cm² (95% CI [0.19, 1.24]) for the dominant limb. Interpretation of results can be found in Table 3.

Table 2 Demographics

	Preseason	Postseason
N	64	
Soccer	25	
Field Hockey	32	
Volleyball	7	
Age (years)	20.36 ± 1.56	20.66 ± 1.53
Height (cm)	168.0 ± 7.2	168.2 ± 7.3
Weight (kg)	66.0 ± 9.39	65.52 ± 8.79
Dominant Limb BMD (g/cm ²)	1.21 ± 0.10	1.22 ± 0.10
Soccer	1.17 ± 0.09	1.17 ± 0.09
Field Hockey	1.23 ± 0.08	1.22 ± 0.07
Volleyball	1.35 ± 0.10	1.37 ± 0.09
Non-Dominant Limb BMD (g/cm ²)	1.21 ± 0.09	1.21 ± 0.09
Soccer	1.16 ± 0.07	1.17 ± 0.07
Field Hockey	1.23 ± 0.08	1.23 ± 0.08
Volleyball	1.32 ± 0.06	1.33 ± 0.04

Abbreviations: cm, centimeter; kg, kilograms; g, grams.

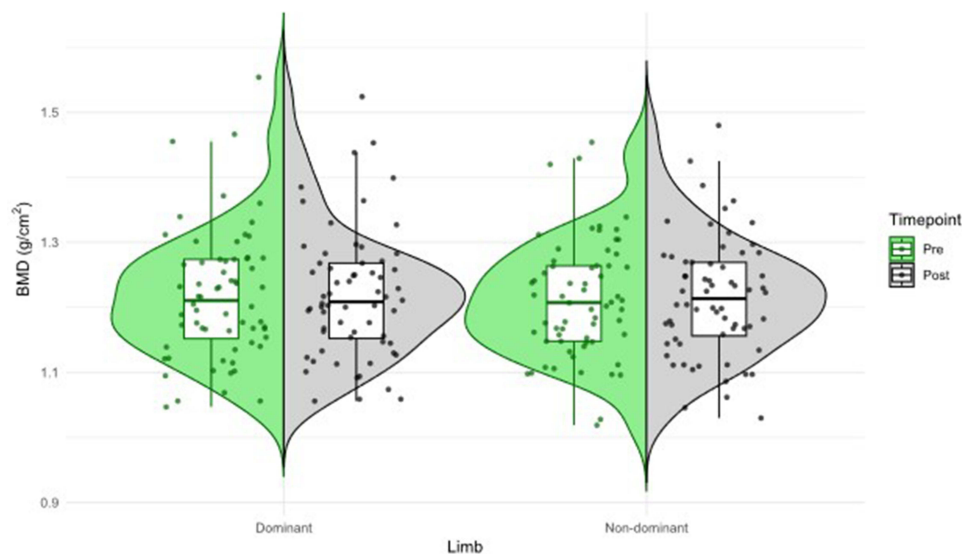


Figure 1 Bone mineral density (BMD) changes from preseason to postseason across all Division I female athletes combined (field hockey, soccer, and volleyball). Data represent dominant and non-dominant lower limbs and are displayed as violin plots with overlaid boxplots and individual data points for each time point.

Discussion

This study examined seasonal changes in lower limb BMD among Division I female athletes by comparing DXA scans taken at preseason and postseason time points. Despite the demands of training and competition, our findings revealed no statistically significant changes in lower limb BMD, which does not support our hypothesis that measurable changes of BMD would occur over the course of the season. However, we did observe that there was a main effect of limb, which indicates a statistically significant difference in BMD between the dominant and nondominant limbs. Although these results found no significant differences between pre- and postseason lower limb BMD, this is the first study to report pre- and postseason BMD across a range of sports in female collegiate athletes, and comprehensive and descriptive overview of BMD in a typically understudied and at-risk population.

Previous research examining BMD changes in athletes from different sports and age groups has produced mixed results. In a previously published longitudinal study on competitive cyclists and found no significant total body BMD changes between pre- and postseason (7 months),¹⁹ which aligns with our findings. A similar study to ours assessed BMD at three time points (off-season, preseason, and postseason) in female Division I athletes in varying sports (softball, basketball, volleyball, swimming, and track and field) and found that lower limb BMD in volleyball players was significantly different from off-season ($1.51 \pm 0.08 \text{ g}\cdot\text{cm}^{-2}$) and preseason ($1.52 \pm 0.08 \text{ g}\cdot\text{cm}^{-2}$) to postseason ($1.55 \pm 0.09 \text{ g}\cdot\text{cm}^{-2}$).²⁰ Similarly, they reported a significant difference between preseason ($1.23 \pm 0.09 \text{ g}\cdot\text{cm}^{-2}$) and postseason ($1.24 \pm 0.09 \text{ g}\cdot\text{cm}^{-2}$) lower limb BMD in swimming athletes. Lastly, they found significant difference across all three time points in track and field athletes (Off-season: $1.46 \pm 0.08 \text{ g}\cdot\text{cm}^{-2}$; Preseason: $1.47 \pm 0.08 \text{ g}\cdot\text{cm}^{-2}$; Postseason: $1.48 \pm 0.08 \text{ g}\cdot\text{cm}^{-2}$). The differences in results between our study and this previously published work could be due to the

Table 3 2×2 ANCOVA

	F (1,61)	p-value	Partial η^2	Interpretation
Time (Preseason vs Postseason)	0.80	0.38	0.013	Not significant
Limb (Dominant vs Nondominant)	4.45	0.04	0.068	Significant
Time × Limb Interaction	0.09	0.76	0.001	Not significant

Notes: Results of the 2×2 ANCOVA testing Time (preseason vs postseason) and Limb (dominant vs nondominant) effects on the outcome. There was a significant main effect of Limb, indicating between-limb differences. The main effect of Time was not significant, and the Time×Limb interaction was not significant indicating similar preseason-to-postseason changes across limbs.

sports assessed; volleyball was the only common sport between the two studies. Furthermore, our study separates lower limb BMD into dominant and non-dominant values, while they reported leg bone BMD as a whole, which could lead to the differences in results.²⁰ In contrast, a study examined BMD changes over two years in both male and female collegiate athletes (basketball, hockey, and soccer) and found a significant increase in limb BMD.¹⁵ On average the athletes (Right Leg: 1.21 ± 0.09 g/cm² and Left Leg: 1.22 ± 0.09 g/cm²) within our study lower limb BMD values were higher than control individuals (Right and Left Leg: 1.15 ± 0.09 g/cm²) from a previously published study, however, were lower than the athletes (runners, netball, and rugby).²¹ This may highlight how the type and intensity of mechanical loading specific to each sport can influence BMD. Overall, our findings align with studies that reported no significant short-term BMD changes in lower-impact sports, suggesting that detectable bone adaptations may require longer durations between assessments, higher training loads, or participation in more osteogenic sports. Our lack of significant seasonal changes may reflect the shorter follow-up period and sport-specific loading profiles represented in our sample.

Our results revealed a statistically significant difference in BMD between limbs when controlling for sport type; however, the estimated marginal means suggest the actual differences were small, with the dominant limb measuring 1.215 g/cm² (95% CI [1.19, 1.24]) and the nondominant limb 1.217 g/cm² (95% CI [1.19, 1.24]). Notably, when examining limb differences within individual sports, volleyball athletes demonstrated a clear asymmetry between limbs, which may have contributed to the overall significant limb effect. Furthermore, volleyball players exhibited higher BMD values in both the dominant and nondominant limbs compared to athletes in other sports. These findings may reflect sport-specific loading patterns, as volleyball is the only court-based sport in our cohort and involves frequent, high-impact jumping activities that likely promote greater bone adaptation.

While the absence of significant BMD changes over the course of an athletic season suggests sufficient bone maintenance, it is also possible that seasonal training adaptations have a minimal impact on bone mass in this population. Given that these athletes entered the season with healthy baseline BMD, any additional bone accrual may have been minor or difficult to detect within a single season. Furthermore, periodization in training regimens, impact loading, such as jumping or sprinting activities,^{4,22} and individual differences in bone remodeling rates may have contributed to the observed stability. Future studies should explore these alternative measures to develop a more comprehensive understanding of how collegiate sports participation influences long-term bone health. The limited timeframe between preseason and postseason assessments, as it was only 126.5 ± 13.4 days between scans, may have contributed to the lack of significant BMD changes. This highlights the need for extended study durations to assess long-term trends in collegiate athletes. Extending the study duration by conducting more extensive longitudinal assessments of BMD across multiple seasons could provide a more comprehensive understanding of training-related bone adaptations.

Several limitations should be considered when interpreting these findings. One limitation is the lack of nutritional and recovery data, as bone health is influenced by dietary intake (eg, calcium, vitamin D, protein), training load, and recovery factors such as sleep and stress. Since nutritional habits and recovery metrics were not monitored, their potential impact on BMD cannot be characterized in this study. To address this, future research should incorporate detailed assessments of dietary intake and recovery behaviors, including sleep patterns and stress levels, to clarify their role in seasonal BMD changes. Limb-use patterns likely differ across sports, which may have contributed to variability in lower-limb loading and BMD outcomes. Additionally, marital status, pregnancy status, and gynecological conditions were not assessed and may represent unmeasured factors influencing bone health. Future studies should investigate these biological and physiological differences to better understand their contribution to BMD outcomes. Addressing these limitations in future research will help develop a more comprehensive understanding of how training, nutrition, recovery, and individual-specific factors influence bone health in collegiate athletes, ultimately informing targeted strategies for skeletal adaptation and injury prevention.

Conclusion

This study found that lower limb BMD remained stable throughout a competitive season in female Division I athletes, with no significant changes between preseason and postseason assessments. These findings suggest that training and recovery protocols may be sufficient to maintain BMD or that the competitive season is too short to elicit detectable BMD changes. Consistent with previous research, our results reinforce the idea that bone adaptation occurs gradually,

often requiring longer timeframes to manifest. Future research should incorporate longitudinal designs, sport-specific analyses, and assessments of nutritional and recovery factors to further understand the complex interactions influencing BMD in female athletes. A holistic approach to BMD monitoring may provide valuable insights for optimizing performance, reducing risk of injury, and enhancing long-term athlete health.

Data Sharing Statement

Data is confidential.

Ethics Approval

This study was approved by Michigan State University's Institutional Review Board.

Consent to Participate

All participants completed written, and informed consent.

Consent for Publication

All participants completed informed consent regarding the publication of their data.

Acknowledgment

The results of this study are clear, present, and without fabrication, falsification, or inappropriate data manipulation.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This study was partially funded by Nike. Dr. Harkey was supported by a National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS) grant (K01 AR081389).

Disclosure

The authors have no conflicts of interest to report for this work.

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