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A Two-Year Longitudinal Study of Bone Mineral Density in Collegiate Distance Runners

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Abstract

Research has shown that weight-bearing physical activity such as running results in osteogenesis; distance runners, however, may experience deficiencies at specific sites. The purpose of this investigation was to examine changes in bone mineral density (BMD) of male and female collegiate cross-country runners over two years. **Methods**: BMD of 29 collegiate distance runners (16 men and 13 women) were measured five times over 24 months using dual-energy x-ray absorptiometry (DXA) at the anterior-posterior (AP) and lateral (LAT) spine, femoral neck (FN), total hip (TH), whole body (WB), and ultra-distal (UD) forearm. A repeated measures multivariate analysis of covariance, with bone free lean mass (BFLM) as covariate, was used to compare mean BMD values. **Results**: Adjusted for BFLM, there were no significant differences ($p>0.05$) in BMD at any site between sexes. There were no significant differences at the AP or LAT spine, or FN across visits for either sex. There was a significant increase in BMD ($p=0.044$) at the UD forearm over two years in males. However, 56% of the men ($n=9$) had a z-score <-1 at the UD forearm. Seven of 11 women had z-scores <-1.0 at the LAT spine and four of 13 had z-scores <-1.0 at the AP spine. **Conclusion**: There were no significant changes in BMD at any site over the two-year time frame, except the men had a significant increase in BMD at the non-dominant forearm. The spine appears to be an area of concern for the women in this study when examining z-score results.

Word Count: 250

Introduction

The skeletal system plays an important role in overall health across the human life span. Research has shown that over time, however, the skeleton architecture can change and become brittle and subject to fracture (Nattiv et al., 2007). The activities performed early in life, namely the first three decades, can impact the skeleton thereafter. Exercise, especially weight-bearing, high impact activity early in life, is thought to be beneficial to skeletal health, helping to accrue the maximum bone density during the bone formation years (Stanforth et al., 2016). For women, it appears that the skeletal system growth is complete by the age of 20 (Haapasalo et al., 1996). For men it appears that bone growth may continue until the middle of their third decade of life (Barrack et al., 2017). In addition to weight-bearing, high impact activity, energy intake, including a person's calcium and vitamin D intake are important factors in optimizing bone health early in life (McCormack et al., 2017; Pollock, et al., 2010).

The bone health of endurance athletes has been of interest to sports scientists for decades. It has been shown that some of these athletes may experience periods of low caloric intake to control weight gain (Tenforde et al., 2016). This reduced caloric intake impacts bone health through decreased calcium and vitamin D levels, and research has shown distance runners may experience osteopenia and osteoporosis at a young age (Barrack, et al., 2017; Barrack, et al., 2008). Over the past few decades, there have been a number of cross-sectional studies examining the bone mineral density (BMD) of endurance athletes. Some studies have a shown a benefit in BMD at specific sites (Kohrt et al., 2004; Hind et al., 2006; McCormack et al., 2019). Others have shown reduced BMD in distance runners (Barrack et al., 2007; Fredericson et al., 2007; Tenforde et al., 2015, 2018), or that reduced BMD may be site specific, such as at the lumbar spine, when compared with age and size matched controls (Barrack et al., 2008; Fredericson et al., 2007; Hind et al., 2006). Additionally, there have been numerous longitudinal studies examining the BMD of distance runners, with investigation durations ranging from 8 months to 5 years. The populations of these investigations have varied from adolescent runners to adult pre-menopausal women runners, with most of these studies using women participants. One longitudinal study investigated male and female distance runners, power athletes, and controls of collegiate age over a one-year timeframe (Bennell et al., 1997). In a study of female collegiate distance runners, gymnasts, and controls, Taaffe and colleagues (1997) examined BMD changes over an eight-month period. Several longitudinal studies have been conducted on adult elite female distance runners (Pollock et al., 2010; Hind et al., 2011; Sumida et al., 2014). In addition, Barrack and colleagues (2011) conducted a 3-year follow-up of BMD changes in high school women distance runners.

There has been very little research conducted on the BMD changes of collegiate distance runners. These runners may experience many changes in their lives during this time, such as a move away from home and comforts of home-cooked meals and a certain amount of training during their high school years. College brings the possibilities of dining facility meals, more time in classes and associated studying, less rest or sleep time, and changes to the quantity and quality of training. These factors can impact the bone health of these individuals. A recently published examination of the bone health over one-year from a similar population showed that the men maintained BMD across a one-year period (Infantino et al., 2021). The women in that investigation, however, lost BMD at several sites across the one-year period (Infantino et al., 2021).

The purpose of this investigation was to examine the changes in BMD of male and female collegiate distance runners over two years. The results will provide additional data to the limited existing bone health research over this duration of time. The hypothesis of this study was that the men would accrue bone and that the women would lose bone density over the two-year period.

Methods

For this investigation, 29 participants were recruited from an NCAA Division I cross-country team across a four-year timeframe, including 16 male and 13 female runners. Descriptive data for the participants is presented in Table 1 which includes data from visits one and five. The training for this group of distance runners included 10 running sessions per week, with a total weekly mileage greater than 100 km, and several athletes in excess of 120 km. The runners performed cross-training sessions two mornings each week, which consisted of water running or stationary cycling and two resistance training sessions per week.

The five visits within this study were conducted at the beginning of consecutive semesters, beginning in the fall of the runner's freshman or transfer year. The time between visits was four months between the fall semester and spring semester testing and approximately 8 months between spring semester testing and the next fall testing. All participants gave informed consent and the research protocol was approved in accordance with the Helsinki Declaration by the Loyola Marymount University Human Subject's Institutional Review Board.

BMD was measured at six sites: anterior-posterior (AP) spine, lateral (LAT) spine, total hip (TH), femoral neck (FN), whole body (WB), and ultra-distal (UD) non-dominant forearm using dual-energy x-ray absorptiometry (DXA; Hologic Delphi A, Waltham, MA, USA). The machine was calibrated daily using a spine phantom prior to any testing. The same laboratory technician performed all the scans and this technician has a coefficient of variation of $< 1.5\%$.

The WB DXA scan was used to determine percent body fat and bone-free lean mass (BFLM). Z-scores were used to compare the participants in this investigation with healthy age, sex, and ethnicity-matched norms. A z-score < -1.0 was used to identify those participants with low bone density as has been described in previous research (Nattiv et al., 2007). At baseline, athletes gave a history of sports and exercise-related bone injuries. At each subsequent visit, athletes were asked about injuries over the preceding reporting period. In addition, the female runners were asked to complete a menstrual history questionnaire. The women were categorized by menstrual cycle as either eumenorrheic (10 to 12 cycles per year), irregular, which included oligomenorrhea (4 to 9 cycles per year) and amenorrhea (less than 3 cycles per year or no period over the past 3 months), or contraceptive users.

A repeated measures multivariate analysis of covariance, with BFLM as covariate, was used to compare the mean BMD values between sexes and across visits. BFLM was used as the covariate due to its correlation with BMD at the measured sites ($r = 0.427$ to 0.674, $p < 0.021$). All analysis was carried out utilizing IBM SPSS Statistics for Windows version 24 (IBM Corp., Armonk, N.Y., USA). A repeated-measure analysis of variance was used to determine changes in demographic data across the five visits. Significance was set at an alpha level of 0.05 for all tests.

Results

Baseline

At baseline the men runners were taller, heavier, had higher BFLM, and lower body fat than the women runners. Both groups were equal in age and BMI (Table 1). There were no differences in BMD, when adjusted for BFLM, between men and women at any of the six sites at baseline (Figures 1-6). Five of the men (31%) and five of the women (38.5%) had a previous stress fracture/reaction prior to college. Baseline menstrual status of the women is presented in Table 1. One of the women who was eumenorrheic had a previous stress fracture/reaction, the two women who had irregular menstrual cycles at baseline had a previous stress fracture/reaction, and two of the women using oral contraceptives had experienced a stress fracture/reaction prior to joining the investigation. At the first visit, four of the female runners had z-scores < -1.0 at the AP spine, two at the WB, and one each at the FN and TH (Table 2). These eight z-scores < -1.0 occurred in four female runners, one eumenorrheic runner had two z-scores < -1.0 (AP spine and WB), one of the female runners that had irregular menstrual function had a z-score < -1.0 at the AP spine and the other female runner with an irregular menstrual function had four z-scores < -1.0 (AP spine, FN, TH, and WB), and one female runner on oral contraceptives had a z-score < -1.0 at the AP spine. There were three men who had a z-score < -1.0 at visit one and they were all at the AP spine. None of these men had a previous stress fracture/reaction. Calcium nor vitamin D intake did not correlate with any of the BMD measurements at baseline.

Longitudinal

Over the two years the men grew taller, gained weight, increased BFLM by 2.8%, and reduced body fat by 4.6%. The women gained weight (3.4%) with most of it being an increase in BFLM (2.6%) and had a change in BMI (Table 1). Across the two years, when adjusted for BFLM, there were no significant differences in BMD between the male and female runners at any visit at any site (Figures 1-6). There was only one BMD measure that reached a statistically significance difference between visit 1 and 5, which was a significant BMD increase at the U/D forearm in the men (Figure 6). However, there were several significant changes across the two years in the men and women (Figures 1-6). Of note were the non-significant decreases in BMD at the FN (-1.3%, Figure 3), TH (-1.6%, Figure 4), and WB (-1.9%, Figure 5) in the female runners and at the FN (-1.7%, Figure 3) in the male runners over the two years. The spine results were positive with the female runners having non-significant increases at the AP (+1.3%, Figure 1) and LAT (+1.9%, Figure 2) spine and the male runners having a non-significant increase at the AP spine (+0.9%, Figure 1).

When examining z-score results (Table 2), by visit five, there were only two men that had z-scores < -1, one at the AP spine and one at the WB. However, over 50% of the male runners had z-scores < -1.0 at the UD forearm. Even though there were non-significant increases of BMD at the AP and LAT spine in the female runners, 31% (n = 4) had z-scores < -1.0 at the AP spine and 64% (n = 8) had z-scores < -1.0 at the LAT spine at the end of two years. At visit five, 27% (n = 3) of the female runners had z-scores < -1.0 at the U/D forearm.

Over the two years of the study, nine of the runners (31%) had a stress reaction/fracture. Of those nine who sustained a stress reaction/fracture, six were women (46% of the female runners) and three were men (19% of the male runners). One woman sustained two stress reaction/fractures and one woman sustained three stress reaction/fractures. There were a total of 12 stress reaction/fractures across the two years of the study. Eight (67%) of the stress reactions/fractures occurred during the first year of the study, four each in the fall and spring of the first year. No stress reactions/fractures occurred during the second fall (cross-country season), and four (33%) occurred during the second spring (track season). Of the 12 bone injuries, four were in the right tibia, four in the left tibia, two in the 4^{th} metatarsal of the left foot (same individual), one in the left femur head, and one in the lumbar spine. Of the six women that sustained a stress fracture, two were experiencing irregular menstrual function when their stress fracture occurred, two were eumenorrheic, and two were on oral contraceptives.

The number of women who were eumenorrheic was six throughout the study. The number of women on oral contraceptives started at five at visit one and went down to three at visit five. The number of female runners experiencing irregular menstrual function changed from two at visit one, to four at visit two (the beginning of the spring semester), and to three for the remainder of the study.

Discussion

The results of this investigation revealed that over the two-year timeframe, this sample of collegiate distance runners was able to maintain their BMD at the six sites tested and the men continued to accrue bone at the U/D forearm. However, there were a few areas of concern. The TH and WB measures for the women had significant decreases in the middle of the study, with the women having a significant decrease at the TH between visits 2 and 5 and a significant decrease at the WB between visits 2 and 3, with no subsequent significant increases. When adjusted for BFLM there were no statistically significant differences in BMD between the female and male runners in this sample of collegiate distance runners.

Baseline

At baseline, this group of collegiate distance runners are similar in size and BFLM and are running the typical mileage of competitive collegiate distance runners (Dengel et al., 2020). The BMD results from this group of distance runners is in line with the data reported by Dengel et al. (2020) in a large-scale investigation into BMD of collegiate athletes. The z-scores at baseline indicate that in these female runners, there may be an issue at the AP spine. Four of the female runners (31%) had z-scores < -1.0 at the AP spine. This finding supports previous research about the lumbar spine being an area of concern in distance runners (Fredericson et al., 2007; Hind et al., 2006). For the male runners there were only three men having a z-score < -1.0 at baseline, all at the AP spine, pointing out a site of concern for distance runners.

The initial menstrual status of the women in this study is comparable to that seen in past research, including the work of Bemben et al. (2004) who reported 7 of 10 runners eumenorrheic and 3 of 10 female runners experiencing menstrual irregularities, and Barrack et al. (2011) who reported 28 of 39 female runners eumenorrheic and 11 of 39 (28%) female runners experiencing menstrual irregularities. The cohort of the present study differs from the work of Gremion et al. (2001) who reported 36% of their female runners experiencing menstrual irregularities and only 33% being eumenorrheic and Pollock et al. (2010) who reported 63% of their female runners experiencing menstrual irregularities.

Longitudinal

To our knowledge, there have been no investigations examining BMD of male and female collegiate distance runners over a two-year timeframe. In this cohort of collegiate distance runners, the men maintained their BMD over the two years and even had an increase in BMD at the U/D forearm. In examining the changes in BMD at the lumbar spine, an area of concern in distance runners (Fredericson et al., 2007; Hind et al., 2006), the men had a statistically non-significant increase in BMD at the AP spine and non-significant decrease in BMD at the LAT spine. The site of concern for the men in this cohort may be the FN, where there was a non-significant decrease of 1.7% over the two years. It could be expected that the FN and TH would increase in male distance runners over the two years of the study. Previous research has shown that men may still be accruing BMD in their early twenties (Barrack et al., 2017). However, the men had zero z-scores at the FN and TH < -1.0, so compared with men of similar age and ethnicity, they have adequate BMD. In research by Infantino et al. (2021), it was reported that men had higher BMD at the TH than age and size matched controls, showing that impact forces of running may be beneficial to BMD.

The z-scores at the AP spine may suggest an area of interest in male distance runners. Comparable to baseline, at visits two and three, three men had z-scores < -1.0. However, this decreased to two and then one male at visits four and five, respectively. An interesting finding was that three male runners (19%) had z-scores < -1.0 at the WB at visit two, the beginning of their second semester. This may be due to several reasons including the transition from high school to college life with a probable increase in training load and possible impacts on the diet and rest patterns of these runners. With the lack of longitudinal BMD data on male distance runners, there is a continued need to collect this data in order to address the concept of Relative Energy Deficiency in Sport (RED-S). The energy availability of a larger sample of this group of collegiate distance runners can be found in the investigations by McCormack and colleagues (2019) and by Beermann et al. (2020).

The female runners in this cohort did not have any statistically significant changes in BMD between visits one and five, however, there was a significant decrease in BMD between visits two and five at the TH and a significant decrease in BMD at the WB between visits two and three. Similar to the male runners at the FN, it could be expected that distance runners would have enhanced BMD at the TH due to the stresses on the femur during running. In examining the z-scores of the female runners, the two sites that stand out are the AP spine and WB. Throughout the two years, four or five female runners had z-scores < -1.0 at the AP spine and two to four women had z-scores < -1.0 at the WB. Previous research has identified the lumbar spine as an area of concern for distance runners due to relative loading status of the site (Fredericson et al., 2007; Hind et al., 2006).

In the female runners there were 47 z-scores < -1.0 across the five visits. Six women accounted for these scores. Twenty-eight (60%) of these scores were in women that were experiencing irregular menstrual function at the time. Twelve (25%) were in women using oral contraceptives, and seven (15%) were in women experiencing eumenorrhea. Also, of the 47 z-scores < -1.0, 37 (79%) were at the AP spine and WB.

Four women (31%) experienced menstrual irregularities at some point across the investigation. At visit one there were two women experiencing menstrual irregularities, which doubled to four women at visit two, then settled at three women for the remainder of the investigation. One woman encountered menstrual irregularities throughout the investigation and two other women began experiencing menstrual irregularities at visit two and continued to the end of the study.

Across the two years there were twelve reports of stress fractures/reactions in nine runners. Three male runners (19%) sustained a stress fracture over the two years of the study, all in the tibia and all in the first year, two in the fall cross-country season and one in the spring track season. These three male runners had calcium intake above the recommended daily allowance (RDA) for adults. However, two of the three men had vitamin D intakes less than the RDA, although running in southern California may have exposed the runners to adequate vitamin D through sunlight. An observation of note in the female runners was that of the four women who experienced menstrual irregularities at some point during the study, two of them had a stress fracture/reaction, with one of these women experiencing two stress fractures/reactions, one in each tibia, and both occurring during the spring track season, one year apart. These results demonstrate that the disruption of the hormonal cycle appears to have an impact on bone formation in this young, healthy population.

One of the limitations to this investigation is the sample size. A better comparison of the women classified by menstrual function could have been possible with a more robust study population size. Additionally, blood analysis of testosterone in the men and vitamin D status in both the men and women collegiate distance runners could provide insight into the BMD changes of the participants throughout the study.

This investigation found that this population of collegiate distance runners maintained their BMD at the anterior-posterior spine, lateral spine, femoral neck, total hip, whole body and ultra-distal forearm, and the men accrued bone at the U/D forearm over the two years. During the study, however, the women experienced significant decreases in BMD at different sites, with a significant decrease at the TH between visits 2 and 5 and at the WB between visits 2 and 3. Neither of these decreases were followed by significant increases. Two the four women who experienced menstrual irregularities at some point throughout the study sustained one stress fracture/reaction, and one sustained two stress fractures/reactions. This result suggests that disturbances of the hormonal cycle could affect bone formation in this population. Further longitudinal research should investigate the impact of energy intake, vitamin D status, and hormonal variations on the changes in bone mineral densities of collegiate distance runners to determine if these findings are representative of a larger population.

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Table 1. Descriptive Data (Mean ± SD)

Variable	Women (n=13)	Men (n=16)
Months v1 to v2	4.1 ± 0.6	4.2 ± 0.6
Months v1 to v3	11.6 ± 0.7	11.5 ± 0.7
Months v1 to v4	15.6 ± 0.6	15.9 ± 0.6
Months v1 to v5	23.6 ± 0.4	23.8 ± 0.4
Age at v1 (yrs)	18.9 ± 0.9	18.9 ± 0.6
Age at v5 (yrs)	20.9 ± 0.8	20.9 ± 0.6
Ht at v1 (cm)	162.8 ± 6.7	177.5 ± 5.9*
Ht at v5 (cm)	163.2 ± 6.6	178.1 ± 6.3*#
Wt at v1 (kg)	52.9 ± 5.5	65.7 ± 5.3*
Wt at v5 (kg)	54.9 ± 5.5#	66.9 ± 5.8*#
BMI at v1	20.0 ± 1.5	20.8 ± 1.5
BMI at v5	20.6 ± 1.8#	21.1 ± 1.5
BFLM at v1 (kg)	39.2 ± 4.2	53.7 ± 4.3*
BFLM at v5 (kg)	40.2 ± 4.0#	55.2 ± 4.2*#
BF at v1 (%)	22.9 ± 2.7	15.1 ± 1.5*
BF at v5 (%)	23.4 ± 4.0	14.4 ± 1.7*
Total Ca++ (mg/d)	1,374.3 ± 546.6	1,524.0 ± 422.8
Total Vit. D (IU/d)	369.3 ± 296.9	351.1 ± 197.7
Ethnicity (n/%):		
White	7 (54%)	12 (75%)
Hispanic	5 (38%)	3 (19%)
Asian	1 (8%)	1 (6%)
v1 Menstrual Status (n %)		
Eumenorrhea	6 (46.2%)	N/A
Irregular	2 (15.4%)	N/A
OC	5 (38.4%)	N/A
v5 Menstrual Status (n %)		
Eumenorrheic	6	N/A
Irregular	3	N/A
OC	3	N/A

* Significant difference between men and women;
\# Significant difference between visit 1 and visit 5

Table 2. Number (and percent) of participants with a z-score < -1.0.

	v1	v2	v3	v4	v5
AP Spine					
Men	3/16 (18.8%)	3/16 (18.8%)	3/16 (18.8%)	2/16 (12.5%)	1/16 (6.3%)
Women	4/13 (30.8%)	4/13 (30.8%)	5/13 (38.5%)	5/13 (38.5%)	4/13 (30.8%)
LAT Spine					
Men	N/A	N/A	N/A	N/A	N/A
Women	N/A	1/2 (50%)	3/4 (75%)	6/8 (75%)	7/11 (63.6%)
FN					
Men	0/13	0/13	0/13	0/13	0/16
Women	1/9 (11.1%)	1/9 (11.1%)	1/9 (11.1%)	1/12 (8.3%)	1/12 (8.3%)
TH					
Men	0/13	0/13	0/13	0/13	0/16
Women	1/9 (11.1%)	1/9 (11.1%)	1/9 (11.1%)	1/12 (8.3%)	1/12 (8.3%)
WB					
Men	0/16	3/16 (18.8%)	0/16	1/16 (6.3%)	1/16 (6.3%)
Women	2/13 (15.4%)	4/13 (30.8%)	3/13 (23.1%)	3/13 (23.7%)	3/13 (23.7%)
FOREARM					
Men	N/A	2/3 (66.7%)	5/6 (83.3%)	3/10 (30.0%)	9/16 (56.3%)
Women	0/1	1/2 (50.0%)	2/4 (50.0%)	3/8 (37.5%)	3/11 (27.3%)

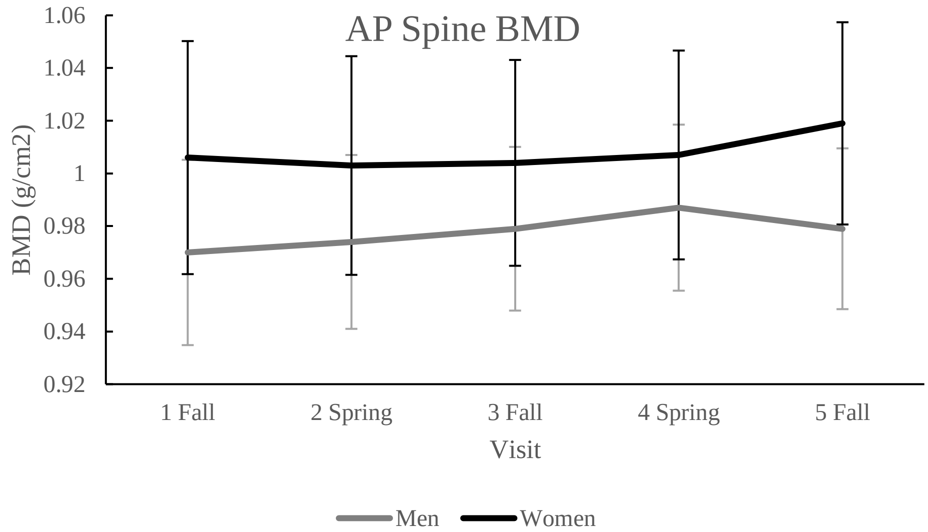

Figure 1. BMD adjusted for bone-free lean mass at the anterior-posterior spine.

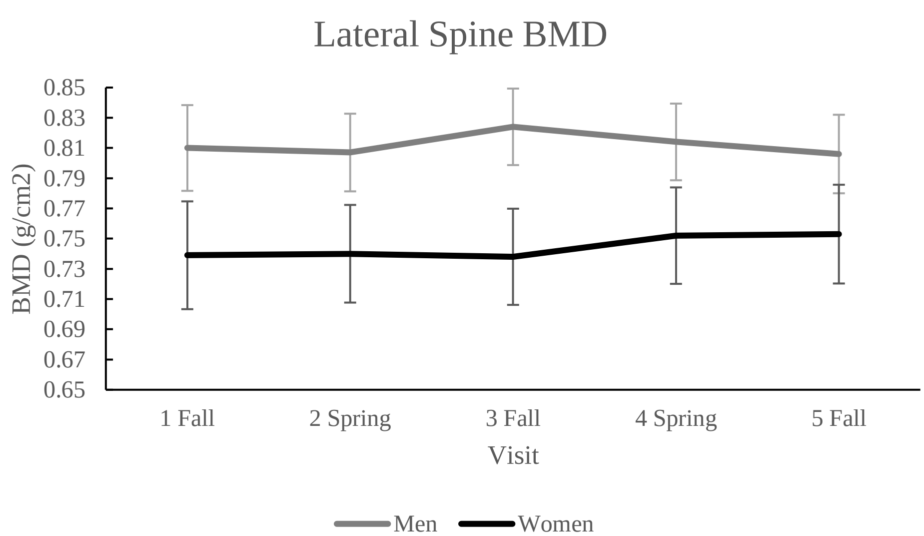

Figure 2. BMD adjusted for bone-free lean mass at the lateral spine.

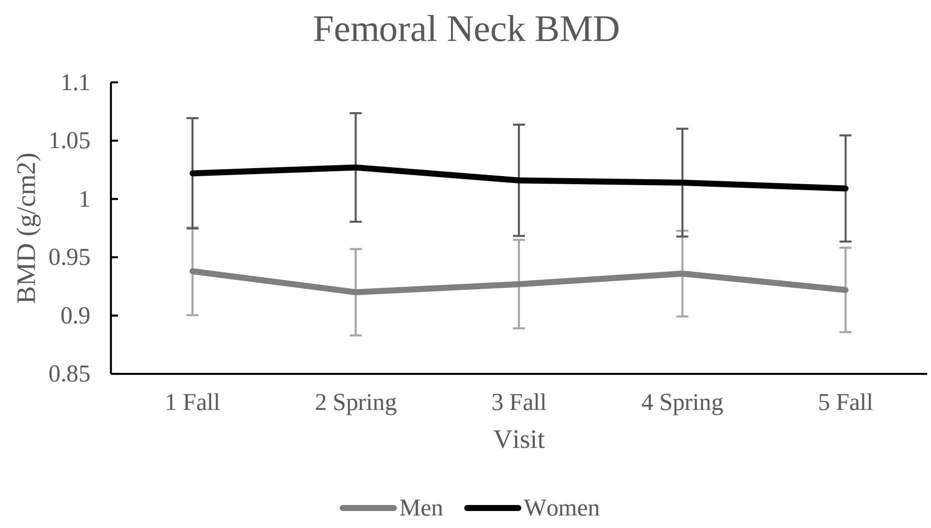

Figure 3. BMD adjusted for bone-free lean mass at the femoral neck.

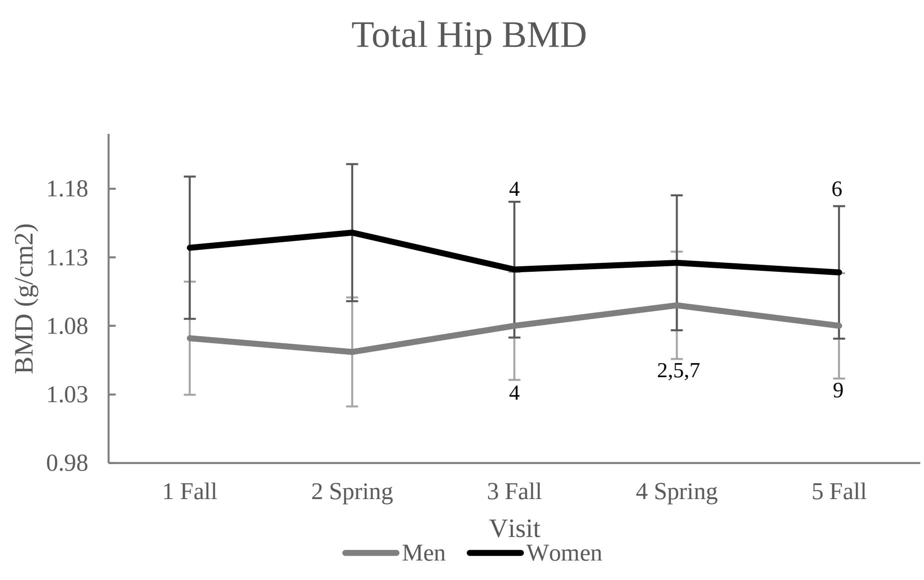

Figure 4. BMD adjusted for bone-free lean mass at the total hip. 2 = v1 and v4 sign. diff.; 4 = v2 and v3 sign. diff.; 5 = v2 and v4 sign. diff.; 6 = v2 and v5 sign. diff.; 7 = v3 and v4 sign. diff.; 9 = v4 and v5 sign. diff. ($p \leq 0.05$).

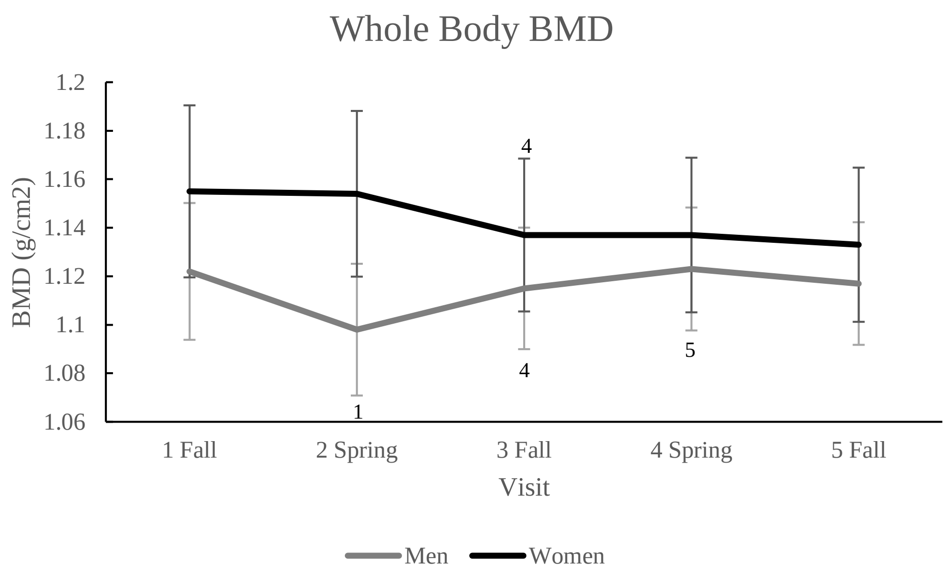

Figure 5. BMD adjusted for bone-free lean mass at the whole body. 1 = v1 and v2 sign. diff.; 4 = v2 and v3 sign. diff.; 5 = v2 and v4 sign. diff. ($p \leq 0.05$).

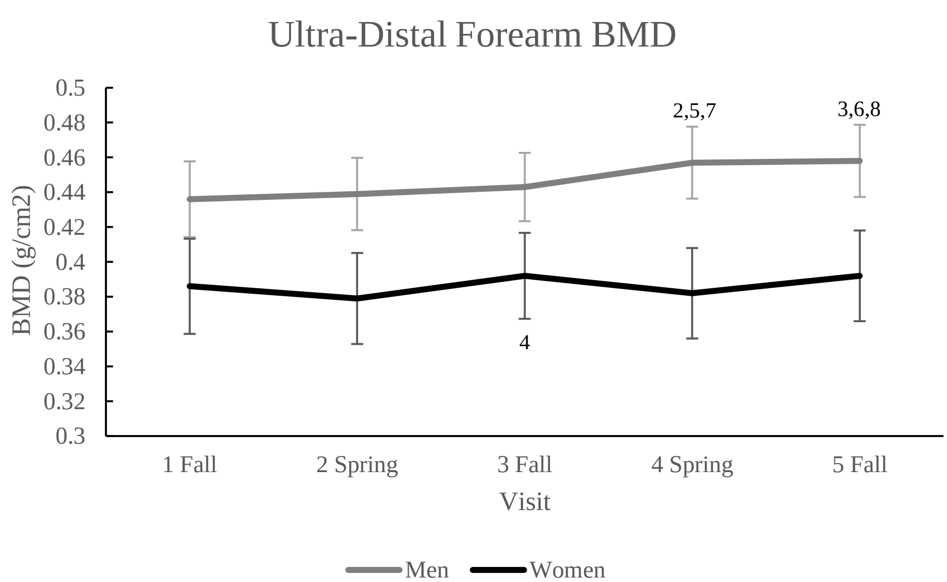

Figure 6. BMD adjusted for bone-free lean mass at the ultra-distal forearm. 2 = v1 and v4 sign. diff.; 3 = v1 and v5 sign. diff.; 4 = v2 and v3 sign. diff.; 5 = v2 and v4 sign. diff.; 6 = v2 and v5 sign. diff.; 7 = v3 and v4 sign. diff.; 8 = v3 and v5 sign. diff. ($p \leq 0.05$).