Bone Mineral Density at the Distal Radius in Female Collegiate Ice Hockey Athletes

A Senior Honors Thesis

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By: Becky Allis

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Dr. Jackie Buell, School of Health and Rehabilitation Sciences, Advisor
Dr. Kendra McCamey, Committee Member
Jennifer Klosterman-Lando, Committee Member

ABSTRACT

Background: Low bone density in the distal radius has been associated with higher risk for fracture. Research suggests that bone density can be increased through weight-loading the bone via resistance training. In the Ohio State sports nutrition lab, female collegiate hockey players have previously demonstrated low bone mass at the wrist in many players. Because women's ice hockey is a contact sport, players are subjected to frequent high-impact collisions, increasing their risk of injury.

Aim: This protocol was designed to formally monitor the distal radius bone mass of female collegiate hockey players over the course of the season. It was expected that by implementing a program designed to add extra loading to the forearm and wrist over the second half of the 2013-2014 season, we would see a trend to increase BMD at the distal radius from midseason to postseason.

Methods: A pre-test/mid-test/post-test design was implemented, with measurements taken in September, January, and March. Dietary intakes were estimated using the VioScreen computerized Food Frequency, and athletes were measured for serum vitamin D in early January. Bone density was measured prior to beginning the program pre-season, mid-season, and post-season using the GE Lunar iDXA scan. The first half of season did not include any extra weight-loading exercises of the upper extremities to act as a control time period while the plan for the second half of season included a higher volume of wrist weight-bearing exercises.

Results: Pre-season measures of this athlete cohort demonstrated 33% (6/18) had low bone mass at the wrist. The mid-season wrist measures demonstrated lower densities for many players, with half of the athletes showing decreased bone density at the wrist and 8 players meeting criteria for low bone mass. The post-season wrist measures showed increased bone densities in 9 players, with 4 players maintaining mid-season bone density. However, there were no statistically significant changes in radial BMD across the season when evaluated using repeated measures statistical procedures.

Conclusion: Based on the results of this pilot study, more loading of the distal radius may have benefitted players' bone mass. However, there was likely not enough power to the study due to its short length and the relatively small number of participants.

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INTRODUCTION

Ice hockey is a fast sport that requires athletes to be durable and well-conditioned. As part of the physical evaluation for intercollegiate ice hockey, the sports nutrition group has provided body composition using the GE Lunar iDXA. The initial assessment for new athletes included bone mineral density (BMD) of the total body, hip, lumbar spine and distal forearm. In comparing the distal radius BMD with population norms of the same age (Z scores), a number of players were "low for age" with Z scores less than -1.0. This protocol was designed to monitor bone mass, body composition, and training habits and markers to further explore the possibly influential factors of how distal radius BMD changes across the competitive season.

Nutrition and training variables affect BMD. Strain, in particular through resistance training and bone loading, influences the formation and breakdown of bone. Generally, the more a bone is loaded, the stronger it becomes. Using this knowledge, the training load of the distal radius of the players was tracked across the season to see its effects. Energy availability in terms of calories consumed is an important aspect to maintain bone mass. Adequate levels of vitamin D help sustain systemic calcium, preventing bone breakdown. Dietary intake measures were taken over the course of the season to monitor these variables.

Primary Aim: Observe the change in distal radius bone mass across the competitive season in NCAA Division I female hockey athletes alongside diet, vitamin D status, and weight-training markers.

REVIEW OF THE LITERATURE

Bone density has historically been a good predictor of fracture risk. Augat et al.[5] loaded the radius of 20 forearms from human cadavers until the bones fractured. Measurements of bone mineral content and density showed to be the best predictors of the load when the bone fractured. From this it appears that a lower bone density in the radius puts one at a higher risk for fracture in an impact situation. Based on this, it could be hypothesized that increasing one's bone density, specifically in the radius, would reduce one's risk for radial fracture. Measuring site-specific bone mineral content has shown predictive prospects. Women with a combined low bone mineral content at the distal radius and the calcaneus had a 1 in 4 probability of a fracture of the spine, while women with a combined high bone mineral content at these sites had only a 2 in 1000 probability of spinal fracture[46]. Trivitayaratana & Trivitayaratana[42] found that use of BMD functional for in vivo diagnosis of osteoporosis of the spine, femoral neck, and Ward's triangle. Bone density at the distal radius is not only predictive of radial fractures, but also fractures elsewhere in the body. Evaluating bone density at these sites can indicate that there are bone deficiencies that need to be corrected for overall skeletal health.

In 1987 Harold Frost[16] introduced his "mechanostat" theory. Frost hypothesized that bone has a strain threshold. When bone is strained beyond this threshold, bone formation is stimulated to strengthen the bone and raise the strain threshold. When bone is not strained near this threshold, bone resorption is stimulated which lowers the strain threshold. Thus, the bone adapts to patterns of strain and mechanical load. More recent research has shown that osteocytes react to strain.

When mechanical loading is lower than the strain threshold, osteocytes die, causing bone resorption. When mechanical loading is higher than the strain threshold, osteocytes are maintained and new osteocytes form, strengthening the bone[19]. The type and magnitude of mechanical loading can be interpreted by physiological mechanisms, which then signal to the body to make appropriate adjustments to the osteocyte balance. Based on this research it has been shown that the mechanical load of a movement is more important than the number of repetitions of the movement[37]. This knowledge can be used to develop protocols intended to strengthen bone.

Increased weight-bearing physical activity is associated with higher BMD throughout the body[34]. Certain activities have been shown to have a greater effect on BMD. In particular, the connection between resistance training and increased bone density has been widely examined. Snow-Harter et al.[39] randomly assigned young women (mean age 19.9 +/- 0.7 years) to a running group, a resistance training group, and a control group for 35 weeks. Both the resistance training group and the running group showed significant increases in BMD over the control group, indicating that multiple modalities of physical activity can positively affect bone density. However, there was a larger increase in the resistance-training group, indicating that over the same time period resistance training has a stronger impact on BMD. A two-year study tracking BMD in young active women found a significant difference in the BMD of a group that mostly did stretching and a group that did moderate intensity resistance training and aerobic activity[15]. In addition, it appears that more load has a stronger effect on BMD. Kerr et al.[22] found that a resistance training program that had high load with low number of repetitions had a significant positive effect on BMD in postmenopausal women, but a low load with high number of repetitions did not create any change in BMD. From this, the authors concluded that BMD was significantly increased by adoption of a high load with low number of repetitions resistance training program. In addition, it was found that in college-aged males, a high-intensity resistance-training program was effective in increasing BMD at multiple sites and in the total body; however, a low-intensity resistance-training program had no significant differences from the control group in BMD[43]. Current research strongly supports the connection between resistance training and higher BMD.

Some studies have shown a lack of increase in bone mineral density with resistance training, specifically in premenopausal women. Vuori et al.[45] found that a year-long strength training program focused on exclusively the lower limb had very little effect on bone density throughout the lower body, with the only significant changes post-training compared to a control group occurring in the patella. Overall changes to body bone mineral density were not significantly different from the control group upon completion of the resistance training program, but they were trending toward significance. Vuori et al.[45] also looked at the effects of a 3 month detraining period after the 1 year training program. At the end of the 3 months the insignificant changes in bone mineral density had returned almost to baseline, suggesting that the resistance training had a positive effect on bone density but did not last. Vanni et al.[44] studied 27 women, age 35-44, throughout the implementation of a 28 week resistance training program. Throughout the study they found no significant changes in bone mineral density despite significant increases in one rep max and twenty rep max strength among the women. Blimkie et al.[7] looked at a younger population, 32 post-menarcheal girls aged 14-18 years old. Sixteen of the subjects followed a 26-week progressive resistance training program and 16 served as a control group. Bone mineral density was measured pre and post program in the total body and in the lumbar spine. Again, despite significant increases in strength, there were no significant increases in bone mineral density in the resistance-training group. Interventions to increase bone density do not always show significant increases; this does not mean that there was no positive effect on bone health—many of the studies showed positive trends that did not reach significance. Small changes in bone mass can make big differences in terms of health and fracture risk.

It is commonly assumed that the radius has lower BMD because it is a non-weight-bearing bone, meaning that it is loaded less frequently. Primates have demonstrated that skeletal loading affects forelimb bone density. Some primates use their forelimbs to support their body mass, adopting a quadruped locomotion. These primates experience compressive loads with their arms. On the other hand, suspensory primates use their arms to swing in the tree branches, developing strong forearm muscles. These primates experience contractile loads. When the forearm bones of these types of primates were examined, the quadruped primates exhibited significantly more bone density in the forearm than the suspensory primates, indicating that the skeletal loading of these bones had a stronger effect on bone density than the contractile loading of the bones[9].

While humans likely won't adopt quadruped locomotion to increase their radial bone density, alternative strategies have been examined. The distal radius has shown limited responses to resistance training. Few studies available looked at the effects of a resistance training intervention on bone mineral density specifically at the distal radius. Most previous measurements of the distal radius with intervention were done simply to control for any peripheral bone adaptations that might occur with training; few targeted this area for improvement[33]. Men with a history of weight lifting and exercising for at least a year have showed higher bone mineral density than age-matched controls in the lumbar spine, trochanter, and femoral neck. However, there was no significant difference in bone density found between the exercise group and the control group at the mid-radius, not the distal radius. From these results, the authors concluded that the mid-radius was unaffected by resistance training and exercise because it is not a weight-bearing site[10]. Nickols-Richardson et al.[29] examined bone density in 70 women, aged 18-26, over the course of a 5 month resistance training program of isokinetic exercises. They found that total body bone density increased significantly from the start of the program to the end. This study also measured the changes in the bone density of the total forearm, finding a small but significant increase with training.

Certain athletic activities have demonstrated significant effects on the radius. Young adult female tennis players have shown increased bone mineral density in the humerus of the playing versus non-playing arms, suggesting that the muscular activation of swinging the racket positively affected bone density[14,17]. Young recreational and competitive female gymnasts demonstrated approximately 5 percent higher total body bone mineral content than age-matched controls. In addition, the distal radius of the gymnasts showed 18 percent greater bone mineral content than was observed in the controls[13]. NCAA Division I collegiate female gymnasts had significantly higher BMD at all measured sites—the spine, hip, and total body[6]. The impact and mechanical load exerted on the wrist during gymnastics has an osteogenic effect on bone density likely due to the high impacts and strains.

Diet is an important variable to account for in studies of bone. Calorie consumption within energy availability is important to the maintenance of bone mass[20]. Adequate levels of vitamin

D play an important role in bone health as well[18]. Prior studies have shown that low levels of vitamin D can be detrimental to BMD. Otherwise healthy postmenopausal women with Vitamin D insufficiency show increased bone remodeling and low bone mass, indicating that vitamin D insufficiency is a risk factor for low BMD[28]. The effects of vitamin D have been specifically linked to the distal radius. In one study, vitamin D inadequacy was associated with low-energy distal radius fractures. In particularly, vitamin D in the blood was significantly lower in patients with a distal radius fracture in addition to osteoporosis than in osteoporotic patients with no fracture. There appears to be a connection between serum vitamin D and distal radius fracture risk[30]. A study of healthy premenopausal women in Italy found that nearly 30 percent of the 600 women measured had low serum vitamin D, indicating that low levels of vitamin D are fairly common[2]. Ensuring an adequate vitamin D status promotes bone health.

The VioScreen Food Frequency Questionnaire (FFQ) has been used successfully to evaluate dietary intake in the general population. This FFQ is a convenient and easy to use online tool, accessed anywhere via the internet[1]. When compared with paper FFQs, the VioScreen questionnaire was just as good at measuring intake variables. It also demonstrated strong test-retest reliability for fat, carbohydrate, protein, and alcohol, with correlations of 0.60, 0.63, 0.73, and 0.87, respectively ($p<0.05$), indicating that it can be used to get a good representation of dietary intake over multiple measures[23]. Correlations between the VioScreen energy intake data and data gathered from six 24-hour recalls were moderate ($r=0.44$, $p<0.02$). Correlations were at or about 0.80 for all of the macronutrients except protein, which had a 0.67 correlation ($p<0.02$). Subjects have found it to be an easy to use questionnaire, with an average completion time of 26.7 +/- 10.0 minutes. The VioScreen FFQ has been deemed an accurate assessment for dietary intake[47].

Use of dual-energy x-ray absorptiometry (DXA) to measure bone mass and density has been shown to be a good measure of changes in the qualities of the bone. DXA is the most widely used densitometry technique[12], and it is considered a gold standard for measuring BMD[8]. The vast majority of studies on bone density use DXA as the primary measurement. Repeated measures have shown strong correlation in the upper extremity. Bone mass demonstrated a repeated measures correlation of $r=0.97$ ($p<0.05$) when both measures were conducted in the supine position. BMD exhibited strong consistency across measures as well ($r=0.92$, $p<0.05$)[26]. It is considered to be accurate and precise across time and with body composition changes, though there are margins of error to be considered[8].

Because of the speed and physical nature of the sport, female ice hockey players have shown skeletal adaptations in certain areas of the body. Studies have shown female ice hockey players have higher bone mineral density (BMD) than similar inactive controls in the lumbar spine and hip skeletal sites (trochanter, Ward’s triangle, and femoral neck)[36]. This suggests that playing and/or training for ice hockey has a positive effect on BMD, specifically in the lower limb and around the hip joint. This is likely due to the unique type of loading that occurs with skating. Total body BMD was also higher than that of the controls, likely due to the increased density around the hip joint. However, this study did not examine BMD in the upper extremity. Not much is known about the effects of ice hockey on the upper extremity.

The distal radius was of interest to us because members of the Ohio State women's ice hockey team have historically demonstrated lower than average BMD of the distal radius. This is unexpected in ice hockey because it is a contact sport, and because players activate forearm muscles frequently using the stick. In the 2012-2013 competetive season, 6 of 24 female ice hockey athletes at Ohio State had low bone density in the distal radius of their non-dominant forearm. In addition, Agel et al.[3] found that 30.3% of competition injuries in collegiate women's hockey players were upper extremity injuries, indicating that the upper body takes a significant amount of contact and is at high risk for injury. The radius experiences little to no weight-bearing, making it an ideal bone with which to examine the effects of loading. Sowers et al.[40] found that premenopausal women with a higher baseline bone density in the radius had a smaller decrease in bone density over the next five years than women who had a lower baseline bone density. Increasing the bone density at the distal radius might decrease injury risk in that area of the body, especially later down the line. We thus conducted this study to determine if we could increase bone density at the distal radius among female collegiate ice hockey players through a wrist-loading program implemented in the second half of the season.

HYPOTHESIS

We hypothesize that by implementing a program designed to add extra loading to the forearm and wrist over the second half of the 2013-2014 season, we will see increases in BMD at the distal radius from midseason to postseason.

METHODS

Study Design

The study was a 7 month longitudinal design examining body composition, radial bone mass and the potential effects of loading exercises on distal radius bone density in members of the Ohio State women's ice hockey team, a NCAA Division I program. Eighteen women between the ages of 18 and 23 participated in the study. The study and data collection took place during the 2013-2014 competitive season, beginning in September and ending in early March. A pre-test/mid-test/post-test design was implemented, with measurements taken in September (preseason), early January (midseason), and March (postseason). Each assessment had identical procedures.

Participants and Recruitment

All 23 members of the Ohio State women's ice hockey team were invited to participate. All participation was entirely voluntary, and there were no incentives to participate in the study. Of those invited, 21 players consented to participate in the study. Two of the participants did not complete all 3 data measures, leaving a total of 19 participants. All participants in the study were Caucasian females.

iDXA use for bone mass and body composition

Body composition and bone mass at the non-dominant distal radius was measured using the GE Lunar dual-energy X-ray absorptiometry (iDXA). The iDXA provided data on subjects' lean, fat, and bone mass compartments. In addition to the total body scan, bone mineral density (BMD) of the non-dominant distal forearm was measured with the athlete lying supine. In compliance with machine set-up and programming the distal one-third of the radius was measured, and this study examined the ultra-distal radial site. All three measurements were taken by the same technician on the same densitometer.

VioScreen Food Frequency

At the time of the iDXA scans, the athletes also completed a Vioscreen Food Frequency questionnaire to document the training diet. This questionnaire was accessed online using the subject's ID number and password. The questionnaire took approximately 30-40 minutes to complete at each of the three measurements. Athletes answered questions about their food intake over the past 3 months, and the results allowed for analysis of dietary intake variables such as dietary energy, protein, calcium, and iron, in addition to other nutrients.

Serum Vitamin D Measures

In early January, participants had blood drawn to measure levels of serum vitamin D. Participants reported to the same facility as for their iDXA and had their blood drawn by a trained phlebotomist. The athletes had their blood drawn on a day off from training to minimize effects of blood loss on exercise. Minimal blood was drawn to complete the testing, and the analysis was completed at the Medical Center laboratory.

Exercise program monitoring

The initial intention of the study was to institute an intervention after the mid-season measurement in December where additional exercises were added to the strength-training regimen of the athletes. These exercises were intended to add more loading of the distal radius throughout the off-ice workouts of the women. The volume and intensity of these exercises were recorded by the players on their lifting cards, and compliance was estimated by the strength and conditioning coach. To quantify the wrist loading activities, the bench press and pushups were documented to objective numbers for each half of the season. Pushups were quantified as the total number of repetitions performed in each respective half. Bench press was quantified as the number of repetitions completed multiplied by the ratio of average weight lifted to lean body mass. On-ice training volume was very similar for all players because there was a shared practice time in which all players participated in the same drills; because of this, it was assumed that there were no differences between players for the volume or intensity of practice.

Statistical Analysis

Means are reported for distal radius BMD, lean mass, percent body fat, and calorie intake based on the Vioscreen FFQ. Change across time was evaluated using a repeated-measures ANOVA. Outcome variables to be examined across time were evaluated to ensure the data met the assumption of sphericity (similar to ensuring variances equal) where the p value was desirable at $p>0.05$. If sphericity could not be assumed, the Greenhouse-Geisser model was used. In the case of significant changes across time, post hoc testing would have used a Bonferoni adjustment. For evaluating the potential impact of nutrition and weight training across the season, change variables were created for the first and second half of the season and modeled within Spearman correlation. Significance was pre-defined as p-value less than 0.05 for all testing.

RESULTS

Nineteen female hockey athletes ages 18-23 consented to participate and provided complete data. The demographic information for this cohort is displayed in Table 1.

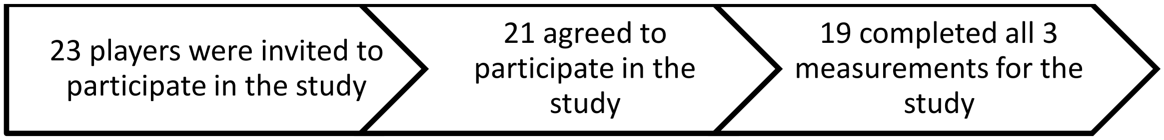


Table 1: Summary of participant demographic data at the commencement of the study

	Average	SD	Range
Age (years)	19.54	1.26	18-23
Ht (inches)	66.7	2.30	64-71
Body weight (pounds)	152.5	10.42	134.25-170.34
BMI (kg/m2)	24.1	1.77	21.7-27.1

Based on the Vioscreen Food Frequency questionnaires, average caloric intakes per participant were less than 2000 calories per day with wide standard deviations (Table 2). It was noticeable that participants did not spend adequate time completing the survey and the outcome variables did not appear robust. For this reason, the nutrition data from these measurements is not considered strong data.

Table 2: Summary of Vioscreen Food Frequency calorie measures

	Average	SD
Preseason	1731.0	510.2
Midseason	1746.1	786.4
Postseason	1535.9	532.1

Training volume for pushups and bench press were evaluated as the weight loading to the distal forearm. From September to December, the average number of pushups completed was 94.25 +/- 35.11; the average bench press volume was 95.96 +/- 40.22. From December to March, the average number of pushups completed was 197.7 +/- 62.66; the average bench press volume was 47.53 +/- 24.27.

To evaluate the potential change of the distal radius across the season, the SPSS General Model for repeated measures was applied. The average value of distal radius BMD based on all of the participants in the study was examined across time assuming sphericity (p=0.215). There were no significant changes across time (p=0.883). There was no change in significance when the model was controlled for January vitamin D as a covariate (p=0.836). The average values of lean mass across the study were also examined across time assuming sphericity (p=0.309). There were no significant changes across time (p=0.311); nor were there significant changes across time with vitamin D as a covariate (p=0.272). The average value for percent body fat based on all of the participants was examined across time using Greenhouse-Geisser (p=0.530) because sphericity could not be assumed (p=0.000). There were no significant changes in percent body fat across time (p=0.310) including when controlled for vitamin D (p=0.331). The means and standard deviations across time for these three variables are shown in Table 3. These average values calculated based on all of the participants do not show much variation over time; however, in some instances individual data shows more variability, as is demonstrated in Figures 1-3.

Table 3: Average values for distal radius BMD, Lean mass, and percent body fat (%Fat).

	Pre-season			Mid-season			Post-season		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Radius	0.4595	0.050	0.391-0.553	0.4639	0.047	0.393-0.550	0.4614	0.052	0.393-0.545
Lean mass	109.4	7.7	92.9-120.6	109.4	8.2	91.9-121.9	109.3	8.7	92.9-125.2
% Fat	24.3	3.0	20.0-35.5	24.2	2.5	20.1-32.8	23.9	2.3	20.4-31.8

Figure 1: Individual measures of BMD at the distal radius at preseason, midseason, and postseason

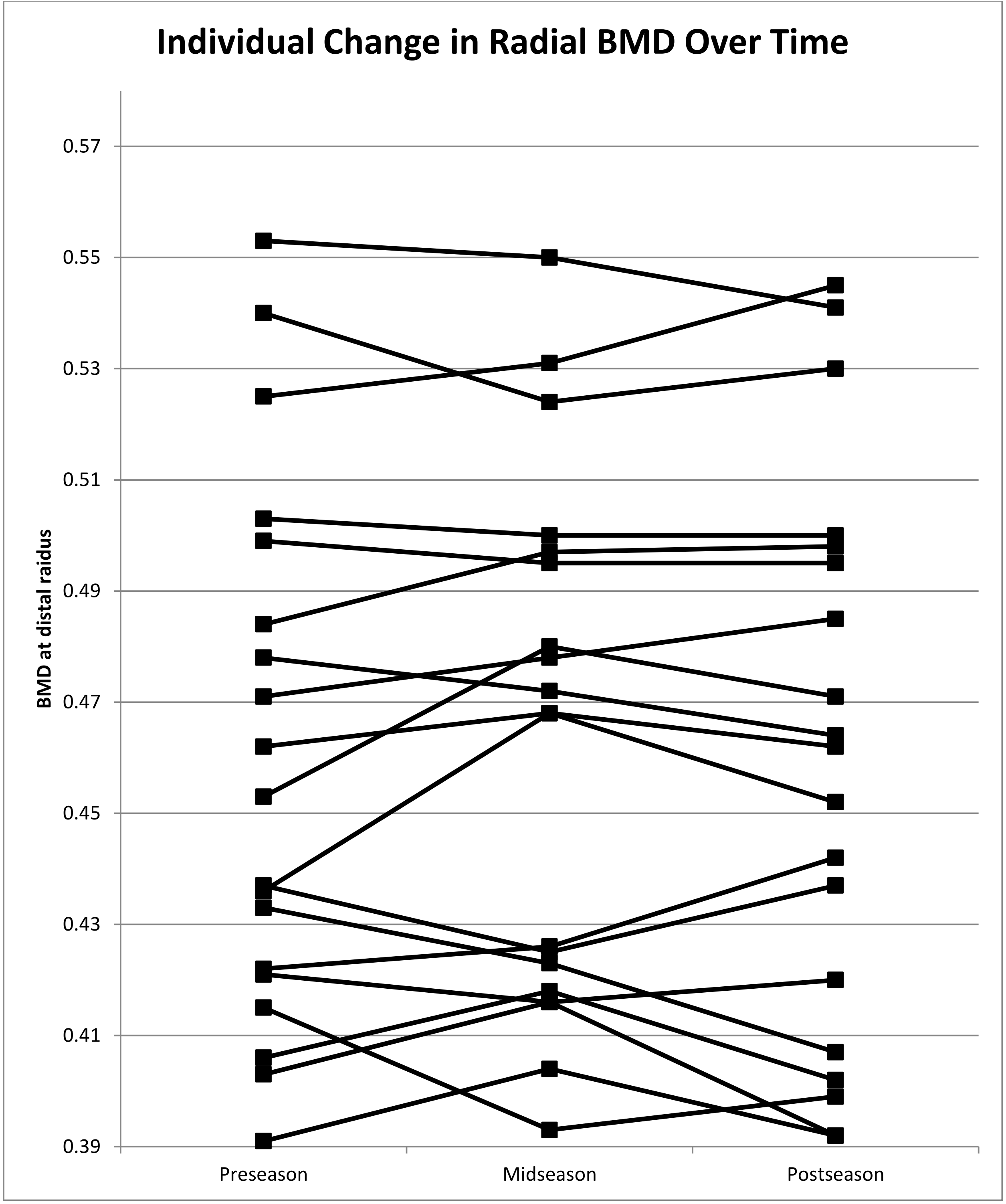


Figure 2: Individual measures of lean mass at preseason, midseason, and postseason

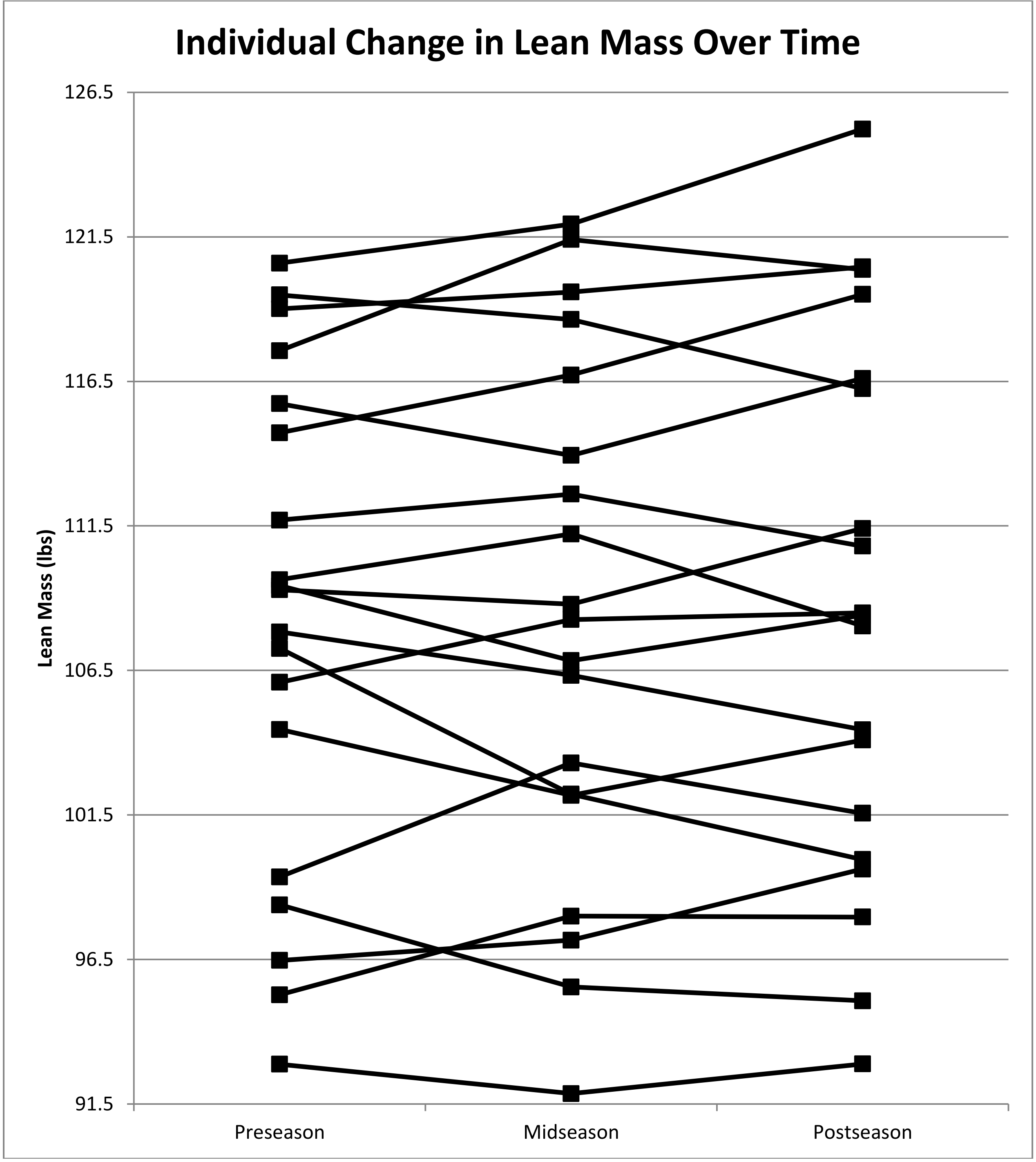
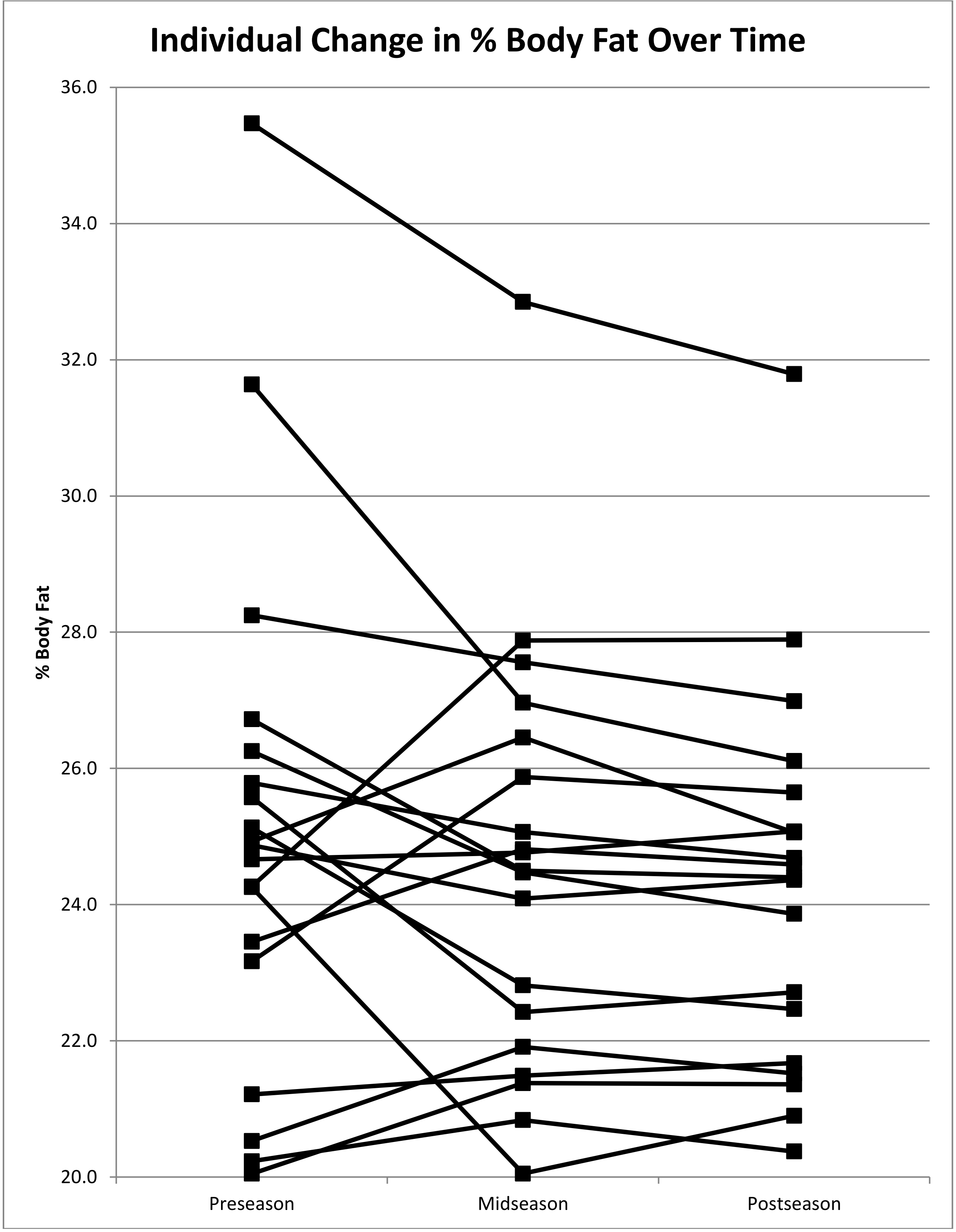


Figure 3: Individual measures of percent body fat at preseason, midseason, and postseason



To evaluate the potential impact of the weight-training program on the distal radius, change variables were computed for the distal radius by subtracting the initial BMD from mid-season BMD measure. The change variable was compared among training variables to reflect weight training, namely bench press and push-up volumes, as well as body composition (lean mass and percent body fat) and nutrition variables (calories consumed and serum vitamin D). Correlations were quantified using the Spearman rank correlation and are detailed in Table 4. There were several significant correlations for the first half of the season. Pushup volume was moderately correlated with change in BMD at the distal radius (r=0.590, p=0.008). Calorie intake was moderately correlated with bench press volume (r=0.524, p=0.037). The correlation between lean mass and percent body fat trended towards a moderate negative correlation that approached significance (r=-0.411, p=0.081). Bench press volume was moderately correlated with serum vitamin D, but did not reach significance (r=0.444, p=0.085). No other correlations approached significance.

Table 4: Summary of correlation data for the first half of the season

		Radius change	%Fat	Lean Mass	Vit D	Bench Press	Pushups	Calories
Radius change	r=	1.000	.388	-.314	.072	.108	.590	-.074
	p		.100	.100	.791	.660	.008	.786
	n	19	19	19	16	19	19	19
%Fat	r=	.388	1.000	-.411	.309	.096	-.032	-.397
	p	.100		.081	.244	.694	.897	.128
	n	19	19	19	16	19	19	19
Lean Mass	r=	-.314	-.411	1.000	-.044	-.202	-.221	.226
	p	.100	.081		.871	.408	.363	.399
	n	19	19	19	16	19	19	19
Vit D	r=	.072	.309	-.044	1.000	.444	.172	.125
	p	.791	.244	.871		.085	.524	.670
	n	16	16	16	16	16	16	16
Bench Press	r=	.108	.096	-.202	.444	1.000	.147	.524
	p	.660	.694	.408	.085		.549	.037
	n	19	19	19	16	19	19	19
Pushups	r=	.590	-.032	-.221	.172	.147	1.000	.152
	p	.008	.897	.363	.524	.549		.574
	n	19	19	19	16	19	19	19
Calories	r=	-.074	-.397	.226	.125	.524	.152	1.000
	p	.786	.128	.399	.670	.037	.574	
	n	19	19	19	16	19	19	19

A similar correlation analysis was performed on the same variables for the second half of the season by computing second half change variables by subtracting the mid-season measures from the post-season measures. Only two correlations were significant in the second half of the season (also in Table 5). Percent body fat was positively correlated with pushup volume (r=0.532, p=0.019). The positive correlation between serum vitamin D and bench press volume made it to significance (r=0.612, p=0.012). No other correlations approached significance.

Table 5: Summary of correlation data for the second half of the season

		Radius change	%Fat	Lean Mass	Vit D	Bench Press	Pushups
Radius change	r=	1.000	.215	.120	-.203	-.023	.197
	p		.376	.623	.451	.926	.418
	n	19	19	19	16	19	19
%Fat	r=	.215	1.000	-.304	.200	.123	.532
	p	.376		.207	.458	.616	.019
	n	19	19	19	16	19	19
Lean Mass	r=	.120	-.304	1.000	-.044	-.181	-.089
	p	.623	.207		.871	.458	.717
	n	19	19	19	16	19	19
Vit D	r=	-.203	.200	-.044	1.000	.612	.150
	p	.451	.458	.871		.012	.578
	n	16	16	16	16	16	16
Bench Press	r=	-.023	.123	-.181	.612	1.000	.233
	p	.926	.616	.458	.012		.337
	n	19	19	19	16	19	19
Pushups	r=	.197	.532	-.089	.150	.233	1.000
	p	.418	.019	.717	.578	.337	
	n	19	19	19	16	19	19

DISCUSSION

The results of this study demonstrate that there were no significant changes in bone density at the distal radius over the course of the season. However, there are some positive indicators that increased loading at the wrist positively affected BMD. The first half of the season was intended to be the part with less wrist loading; however, due to exercise volume changes outside of the control of the researchers, the first half of the season had a higher volume of training. There was a positive trend toward increased BMD at the radius from September to December; it did not approach significance but if similar volumes of training continued through the rest of the season we might have seen continued increases.

After the study, it was obvious that both the first and second halves of the season had wrist-loading activities, and there was an unplanned decrease in weight training activities in the second half of the season. Based on the volume data for pushups and bench press, there was a lot of variability in the volume of wrist loading between athletes. The training program was intended to be the same for all players so that the only differences would be in the amount of weight lifted; however, some of the participants did not complete parts of the program. The main cause of this noncompliance was injury or illness, variables that were outside of our control. In addition, as the season progressed there were fewer lifts and more days off from training. These decisions were entirely based on the discretion of the coaching staff in order to maximize competition performance; again, these changes were outside of our control and not made with the study in mind. Because of these changes, there was an unplanned decrease in wrist-loading activities in the second half of the season. This lack of added wrist-loading volume in the second half could explain why there were no significant changes in BMD during the intervention phase of the study.

Another factor that affected the training volume of the intervention was the tapering of training as the team approached postseason play. From September through December, the players had two strength-training sessions per week in addition to practice four days per week and games two days per week. Beginning in January, resistance training was only performed one day per week, sometimes with a conditioning and strengthening circuit on a second day per week during January. During February there was only one resistance training session per week with no other off-ice training. In addition, on-ice training volume decreased as well because the coaching staff wanted the players well rested for playoffs. This decrease in training volume as the season progressed may have negated the effects of the intervention. Vuori et al.[45] showed in their study that 3 months of detraining following a 1 year resistance training program returned bone density nearly back to baseline levels. The athletes in our study did not have a total detraining period, but their volume of training was decreased for an extended period of time, which may have affected the bone mass measurements in March.

The length of our intervention was also a limiting factor. Liang et al.[25] found that their 10 week upper body resistance training program was sufficient to improve muscular strength but not BMD at the radius or ulna. Kemmler and Engelke's[21] review of resistance training in early postmenopausal women suggests that weight-training interventions to increase bone density significantly should last at least 12 months. A review on pre- and post- menopausal women found a lack of interventions lasting longer than 12 months but suggested that interventions lasting longer than 12 months would be better able to show positive changes in bone density[31]. Lohman's review[27] suggests that 5-12 months of exercise training is sufficient to see significant changes in bone density. The participants of our study were elite athletes and had been doing resistance-training beginning in September, with the intervention beginning in December. We had hoped that the intervention would show results in a shorter time period because of the status of the participants as elite athletes who were already performing exercises that loaded the radius. The intervention was designed to add more volume of these exercises and to emphasize loading of the radius with body weight for the second half of the season. We had hoped to see increases in this December-March intervention; however, it appears that the intervention needed longer and more exaggerated to show significant changes. Instituting the intervention at the start of the season in September and continuing it through the season's end may yield stronger results. Additionally, a properly limited control group would strengthen the study where the control athletes would do everything the same with exception of the bench pressing and pushups. This is not likely an acceptable scenario to the coaches in a Division I athletic program as it might leave those athletes at a strength disadvantage.

Because the Vioscreen Food Frequency Questionnaire yielded such low reported calorie intakes, any further analysis of data from the questionnaire was disregarded. The average calorie consumption reported by the participants at the three measures, shown in Figure 1, was extremely low for elite athletes. In addition, there was a large standard deviation, indicating that there was a lot of variability in the reported caloric intake. Because of this we did not find the VioScreen FFQ to be an accurate representation of the dietary intake of our participants. Weiss[47] had found strong correlations between the Vioscreen FFQ and daily intake; however, our results do not support the accuracy of this FFQ in the over-scheduled collegiate athlete population studied.

In hindsight, measuring serum vitamin D at all three measurement times would have been helpful. Being able to compare changes in vitamin D with changes in BMD may have shown a connection between the two. Because vitamin D was only measured in December, there was no change variable, meaning that we could control for vitamin D based on the single measurement but we could not quantify changes. Being able to quantify for changes in vitamin D would have allowed us to compare it with other change variables like BMD, lean mass, and fat mass most accurately.

The collegiate ice hockey season is long and tiring, beginning in October and ending in March. There is potential for athletes to become fatigued and develop an energy debt as the season goes on. Collegiate athletes are expected to perform at a high level athletically and academically. They have a lot of time demands on them, which may not allow them to get adequate rest and nutrition. Restricted energy availability can have a detrimental effect on bone health and lean mass. Ihle and Loucks[20] found that five days of controlled restricted energy availability caused bone turnover to increase and bone formation to suppress. Energy availability was controlled by having participants burn a set higher amount of calories through exercise than they were allowed to consume. These participants were a similar population to those in our study: young healthy premenopausal women with an average age of 21.4 +/- 0.6 years. It is possible that the participants in our study may have experienced energy deficits over the course of the season, which would have been detrimental to their bone formation. For future studies, better monitoring of caloric intake would help researchers monitor energy availability and counsel athletes so that they do not experience this restricted energy availability.

Another possible limitation of this study was the use of the iDXA for measures of BMD. There is question as to whether DXA—a two-dimensional imaging technique—can truly represent bone strength, a three-dimensional property. A study of rat ulna loading found that a 5 percent increase in BMD measured by DXA correlated with a 94 percent increase in bone breaking strength. This large increase in the strength of the bone with a relatively small increase in the BMD suggests that there are structural changes occurring within the bone that cause a large increase in strength that may not be captured by DXA[35]. Smock et al.[38] examined differences in bone geometry, volumetric density, and estimated bone strength for the tibia in runners and controls. They found that the differences in bone strength between female runners and controls were due to greater bone area rather than BMD measured by DXA. It is possible than DXA cannot capture the structural differences that create stronger bones without necessarily increasing the density of the bone. The use of the iDXA in our study may not have allowed us to measure structural changes within the bone that didn’t affect BMD. Use of peripheral quantitative computed tomography (pQCT), a three-dimensional measurement, might be a better measure.

Future studies on this topic may want to explore the possibilities of multi-vitamin supplementation to include calcium, vitamin D, vitamin A, and vitamin K supplementation at an adequate daily level. Prior research has shown mixed results on the effect of long-term calcium supplements on bone density. Pubertal girls (mean age 12 years) following an 18 month calcium supplementation regimen showed a 1.3% increase in total body bone mineral density compared to age-matched controls and a 2.9% increase in spinal bone density[41]. Postmenopausal women have also demonstrated positive responses to calcium supplementation when taken consistently. These studies have concluded that the calcium helped to prevent age-related loss of bone density, which reduces the risk of osteoporotic fracture[11,32]. A study done on the effects of calcium supplementation on young female distance runners (mean age 23.7 +/- 4.7 years) did not show any increases in bone density but suggested that the increased calcium intake helped prevent bone loss at the femoral mid-shaft[48]. Layne and Nelson suggest that the combination of resistance training and calcium supplementation showed the strongest effect on bone density[24]. Research has suggested Vitamin A and K are important to bone health[4]; future research may want to measure serum levels of these two vitamins and correlate with bone density.

CONCLUSIONS

In conclusion, there were no statistically significant changes in distal radius BMD in female collegiate ice hockey players over the course of the season. Failure of the intervention to increase wrist-loading exercise volume may have limited the results of our study. Future research should have a longer intervention with better-controlled volume of interventional exercises. Continuing to evaluate the relationship of wrist BMD to risk for injury as well as bone strength is of interest in this population of collision athletes.

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