SPORT AND TRAINING INFLUENCE BONE AND BODY COMPOSITION IN WOMEN COLLEGIATE ATHLETES

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ABSTRACT

Carbuhn, AF, Fernandez, TE, Bragg, AF, Green, JS, and Crouse, SF. Sport and training influence bone and body composition in women collegiate athletes. *J Strength Cond Res* 24(7): 1710–1717, 2010—This is a novel descriptive study to characterize off-season, preseason, and postseason bone and body composition measures in women collegiate athletes. From 2006 through 2008, 67 women collegiate athletes from 5 sports, softball ($n = 17$), basketball ($n = 10$), volleyball ($n = 7$), swimming ($n = 16$), and track jumpers and sprinters ($n = 17$) were scanned using dual energy X-ray absorptiometry (DXA) at 3 seasonal periods: (a) off-season = before preseason training, (b) preseason = after preseason training, and (c) postseason = after competitive season. Dual energy X-ray absorptiometry scans were analyzed for total body mass, lean mass (LM), fat mass (FM), percent body fat (%BF), bone mineral content, bone mineral density (BMD), arm BMD, leg BMD, pelvis BMD, and spine BMD. Data were analyzed between sports using analysis of variance (ANOVA) with Tukey post hoc follow-ups, and within each sport using repeated-measures ANOVA and LSD; $\alpha < 0.05$. Significant off-season to preseason or postseason changes in %BF, LM, and BMD within each sport were as follows, respectively: softball, −7, +4, +1%; basketball, −11, +4, +1%; volleyball, unchanged, unchanged, +2%; swimming, unchanged, +2.5%, unchanged; track jumpers and sprinters, −7, +3.5, +1%. Comparisons among athletes in each sport showed bone measurements of swimmers averaged 4–19% lower than that of athletes in any other sport, whereas for track jumpers and sprinters, %BF and FM averaged 36 and 43% lower compared with other sports at all seasonal periods. Values for athletes playing basketball and volleyball were most similar, whereas softball athletes' values fell between all other athletes. These data serve as sport-specific reference values for comparisons at in-season and off-season training periods among women collegiate athletes in various sports.

KEY WORDS DXA, division I, season, female, morphology

INTRODUCTION

It is well documented that participation in women's collegiate athletics may induce changes in bone and body composition (4,7,11,12,14,18). In addition, comparisons among sports have demonstrated distinct bone and body composition dissimilarities in women athletes, which are likely related to sport-specific training practices and body types conducive to sport success (4–6, 11,13,14,18). Significant differences among sports with regard to total body bone mineral density (BMD) have been linked to sport-specific mechanical loading, bone strain, total body mass (TM), and lean mass (LM) (3–6,13,14,19). For example, BMD in lumbar spine and pelvis sites in women endurance runners and swimmers has been shown to be considerably lower compared to that in women in other sports (13). Body composition differences among women in various sports have also been observed and can be attributed to the sport-specific physical requirements, for example, height for volleyball players, physical training required for optimal performance in the sport, and perhaps even a desired sport-specific esthetic body type, for example, gymnastics (6,11,14,18,19). These adaptations in women's bone and body composition as a result of sport participation may also be considered beneficial to their overall health and fitness, possibly reducing the risk of developing certain chronic diseases later in life, such as osteoporosis and cardiovascular disease (8).

Although previously published studies provide important information related to bone and body composition of competitive women athletes, the majority of studies were limited to data measured at a single time period during the training or competitive season. Furthermore, to complicate interpretation of published data the precise measurement time period, with respect to the athletes' training and competition history, was often not specified (1,5,6,13–15,19). This methodological problem renders cross-study comparisons uncertain at best, and could lead to spurious

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conclusions regarding seasonal effects of training in women athletes. Though it is not currently known for most women's sports, it would clearly be of value to document bone and body composition measures during preseason training and again after the competitive season. Such standard chronological measures linked to the training year would have important implications for coaches in the evaluation of the effectiveness of sport-specific training. Also, to the authors' knowledge, there have been no published serial measures of bone and body composition variables in women athletes that included measurements just before initiating preseason training, that is, after the off-season in which some deconditioning invariably occurs. The inclusion of this off-season measurement would be of value not only from a comparative and health perspective, but would also serve to quantify the annual effects of detraining, training, and physical maturation on bone and body composition.

Therefore, the purpose of this study was 2-fold: (a) to serially quantify bone and body compositional profiles of women collegiate athletes over off-season, preseason, and postseason measurement periods; (b) compare and contrast these profiles of women participating in softball, basketball, volleyball, swimming, and track and field.

METHODS

Experimental Approach to the Problem

To determine the sport and training influences on bone and body composition in women collegiate athletes, all women varsity athletes recruited and currently competing at an NCAA Division I university in softball, basketball, volleyball, swimming, and track and field completed multiple dual energy x-ray absorptiometry (DXA) scans yearly in the exercise physiology laboratory. These measurements were required as part of the standard of care for all varsity athletes. The serial DXA measurements were completed at three different seasonal periods operationally defined in this study as: 1) Off-season = assessments completed just before the women began pre-season physical training, 2) Pre-season = assessments completed after pre-season training and just before the beginning the competitive season, and 3) Post-season = assessments made just after the completion of the competitive season. These data were grouped by sport and compared between each sport per seasonal period and also compared all seasonal periods within each sport.

Subjects

The study sample comprised women athletes (*n* = 67) from 5 sports: softball (*n* = 17), basketball (*n* = 10), volleyball (*n* = 7), swimming (*n* = 16), and track jumpers and sprinters (*n* = 17). Data were obtained by permission from the Director of Performance Nutrition in the athletic department with all athletes' identity remaining confidential.

Procedures

All DXA scans were conducted by the athletic department's Director of Performance Nutrition or her trained staff according to the standard DXA protocol at the Sydney and J.L. Huffines Institute for Sports Medicine and Human Performance on the campus of Texas A&M University. The protocol for this study was considered by the Texas A&M University IRB and was deemed exempt from review. Before each scan, all athletes' height and weight were measured using a medical grade standard beam balance scale and its height rod. The DXA-(GE Lunar Prodigy Advance, Madison, WI, USA) derived data for analysis included TM, total body LM, total body fat mass (FM), percent body fat (%BF), total body bone mineral content (BMC), and total BMD with specific BMD sites of importance being arm bone mineral density (ABMD), leg bone mineral density (LBMD), pelvis bone mineral density (PBMD), and spine bone mineral density (SBMD). These specific BMD sites were recorded because of their sensitivity to weight-bearing activity. The DXA measurements were completed on athletes participating in

TABLE 1. Women athletes' demographic characteristics by sport and for all together.

	Total	Softball	Basketball	Volleyball	Swimming	Track jumpers and sprinters
n	67	17	10	7	16	17
Age (y)	20 ± 1 (17–23)	20 ± 1 (18–22)	20 ± 1 (18–21)	19 ± 1 (19–20)	19 ± 1.0 (17–21)	20 ± 2 (17– 23)
Height (cm)	172.3 ± 8.7 (154.9–190.5)	168.8 ± 6.5 (161.3–183.4)	180.1 ± 8.9 (160–190.5)	181.5 ± 5.5 (170.7–186.7)	175.2 ± 6.1 (164.3–185.4)	165.5 ± 5.0 (154.9–177.8)
Body mass (kg)	68.3 ± 9.0 (48–97.9)	69.3 ± 7.0 (55–81.1)	76.9 ± 9.0 (59.1–97.9)	75.7 ± 5.8 (64.2–84.2)	66.4 ± 5.8 (54.6–79.3)	60.5 ± 6.0 (48–72.4)
Body mass index ($\text{kg}\cdot\text{m}^{-2}$)	23 ± 2.4 (17.6–31)	24.3 ± 2.1 (20.7–29.3)	23.8 ± 3.0 (19.8–31)	23 ± 1.8 (18.6–25)	21.6 ± 1.7 (19–24.4)	22.1 ± 2.1 (17.6–26.1)

Means ± *SD* collapsed across all 3 seasonal periods. Ranges given in parentheses under means.

Table 2. Bone and body composition values and *SD*s, including ranges, for softball, basketball, volleyball, swimming, and track and field at all seasonal periods.

	Seasonal period	Softball	Basketball	Volleyball	Swimming	Track and field
Total mass (kg)	Off-season	$68.9 \pm 7.3^{a,*}$ (55–80.2)	$77.1 \pm 10.0^{b,*}$ (59.1–97.9)	$76.0 \pm 5.4^{a,b,*}$ (68.1–83.6)	nd nd	$59.5 \pm 6.4^{c,*}$ (48– 71.4)
	Preseason	$69.5 \pm 7.0^{a,b,c,*}$ (58.1–80.3)	$77.1 \pm 9.4^{a,b,*}$ (59.5–95.5)	$76.3 \pm 6.1^{a,b,*}$ (65.9–84.2)	$67.8 \pm 6.6^{c,d,*}$ (56.1–80.5)	$60.8 \pm 6.0^{d,\#}$ (51.6–72.1)
	Postseason	$69.4 \pm 7.1^{a,b,c,*}$ (56.4–81.1)	$76.3 \pm 8.6^{b,*}$ (62.2–91.4)	$75.0 \pm 6.8^{a,b,c,*}$ (64.2–83.5)	$67.2 \pm 5.7^{c,d,\#}$ (56.9–79.1)	$61.2 \pm 5.7^{d,\#}$ (52.5–72.4)
Lean mass (kg)	Off-season	$46.9 \pm 3.1^{a,*}$ (40.8–52.3)	$53.8 \pm 5.7^{b,*}$ (44.9–62.4)	$51.6 \pm 4.6^{a,b,c,*}$ (44.4–57.8)	nd nd	$47.3 \pm 3.6^{a,c,*}$ (41.6–54.2)
	Preseason	$48.3 \pm 3.3^{a,\#}$ (43.0–54.7)	$55.8 \pm 5.8^{b,\#}$ (46.3–65.1)	$51.2 \pm 4.4^{a,b,c,*}$ (44.4–56.8)	$48.5 \pm 3.8^{a,c,*}$ (41.9–56.0)	$49.0 \pm 3.2^{a,c,\#}$ (43.4–56.1)
	Postseason	$48.6 \pm 3.3^{a,\#}$ (42.8–55.5)	$54.2 \pm 5.6^{b,*}$ (46.3–64.0)	$50.9 \pm 5.6^{a,b,*}$ (43.1–60.4)	$49.7 \pm 4.0^{a,b,\#}$ (43.6–58.0)	$48.9 \pm 3.3^{a,\#}$ (42.7–55.2)
Fat mass (kg)	Off-season	$18.6 \pm 5.7^{a,*}$ (6.8–30.8)	$20.0 \pm 6.6^{a,*}$ (11.5–36.7)	$21.0 \pm 3.4^{a,*,\#}$ (14.8–24.4)	nd nd	$9.4 \pm 3.6^{b,*}$ (4.4–17.5)
	Preseason	$18.1 \pm 5.1^{a,b,c,*}$ (10.3–31.7)	$17.7 \pm 6.3^{a,b,c,\#}$ (10.4–33.8)	$21.8 \pm 4.1^{a,b,*}$ (12.7–24.7)	$15.4 \pm 4.3^{c,*}$ (8.4–23.9)	$8.9 \pm 3.2^{d,*}$ (5.0–15.4)
	Postseason	$17.8 \pm 5.6^{a,*}$ (8.9–32.9)	$18.8 \pm 5.4^{a,*,\#}$ (13–32.3)	$20.2 \pm 3.9^{a,\#}$ (12.2–24.4)	$14.8 \pm 3.5^{a,*}$ (9.1–21.9)	$9.3 \pm 3.1^{b,*}$ (5.1–14.4)
BMC (kg)	Off-season	$2.992 \pm 0.43^{a,*}$ (2.3–3.9)	$3.534 \pm 0.37^{b,*}$ (2.8–4.1)	$3.317 \pm 0.31^{a,b,c,*}$ (3.0–3.9)	nd nd	$2.932 \pm 0.34^{a,c,*}$ (2.0–3.4)
	Preseason	$3.001 \pm 0.42^{a,*}$ (2.4–4.0)	$3.536 \pm 0.35^{b,*}$ (2.8–4.1)	$3.332 \pm 0.32^{a,b,*}$ (2.9–3.9)	$2.590 \pm 0.3^{c,*}$ (2.1–3.4)	$2.958 \pm 0.35^{a,\#}$ (2.1–3.4)
	Postseason	$3.038 \pm 0.44^{a,d,\#}$ (2.3–4.0)	$3.589 \pm 0.45^{b,*}$ (2.8–4.2)	$3.444 \pm 0.29^{a,b,\#}$ (3.1–3.9)	$2.626 \pm 0.28^{c,\#}$ (2.0–3.3)	$2.986 \pm 0.33^{d,\#,\&}$ (2.1–3.4)
BMD ($g\cdot cm^{-2}$)	Off-season	$1.254 \pm 0.08^{a,*}$ (1.14–1.45)	$1.333 \pm 0.06^{b,*}$ (1.24–1.43)	$1.284 \pm 0.06^{a,b,*}$ (1.22–1.42)	nd nd	$1.292 \pm 0.07^{a,b,*}$ (1.13–1.42)
	Preseason	$1.261 \pm 0.08^{a,\#}$ (1.14–1.46)	$1.330 \pm 0.07^{a,*,\#}$ (1.25–1.41)	$1.292 \pm 0.07^{a,*}$ (1.23–1.43)	$1.112 \pm 0.07^{b,*}$ (1.01–1.24)	$1.297 \pm 0.08^{a,*}$ (1.12–1.44)
	Postseason	$1.260 \pm 0.08^{a,c,\#}$ (1.13–1.44)	$1.349 \pm 0.06^{b,c,\#}$ (1.26–1.41)	$1.310 \pm 0.07^{a,b,c,\#}$ (1.24–1.43)	$1.121 \pm 0.07^{d,*}$ (1.00–1.23)	$1.307 \pm 0.08^{a,b,c,\#}$ (1.13–1.44)
Arms BMD ($g\cdot cm^{-2}$)	Off-season	$0.942 \pm 0.07^{a,*}$ (0.846–1.069)	$0.948 \pm 0.04^{a,*}$ (0.901–1.008)	$0.934 \pm 0.04^{a,*}$ (0.879–0.992)	nd nd	$0.897 \pm 0.04^{a,*}$ (0.826–0.967)
	Preseason	$0.944 \pm 0.06^{a,*}$ (0.836–1.052)	$0.946 \pm 0.04^{a,*}$ (0.899–1.000)	$0.929 \pm 0.04^{a,*}$ (0.875–0.990)	$0.857 \pm 0.04^{b,*}$ (0.779–0.951)	$0.910 \pm 0.05^{a,\#}$ (0.847–1.020)
	Postseason	$0.947 \pm 0.06^{a,b,c,*}$ (0.849–1.065)	$0.979 \pm 0.07^{a,b,\#}$ (0.902–1.141)	$0.935 \pm 0.04^{a,b,c,d,*}$ (0.890–0.996)	$0.878 \pm 0.04^{d,\#}$ (0.806–0.971)	$0.914 \pm 0.04^{c,d,\#}$ (0.852–1.012)

Legs BMD (g·cm^{-2})	Off-season	1.424 ± 0.07^{a,*}	1.554 ± 0.08^{b,*}	1.511 ± 0.08^{a,b,*}	nd	1.455 ± 0.08^{a,*}
		(1.319–1.559)	(1.459–1.693)	(1.399–1.609)	nd	(1.321–1.614)
	Preseason	1.425 ± 0.07^{a,*}	1.560 ± 0.07^{b,c,*}	1.518 ± 0.08^{a,c,*}	1.227 ± 0.09^{d,*}	1.465 ± 0.08$^{a,\#}$
		(1.316–1.564)	(1.465–1.710)	(1.400–1.636)	(1.048–1.374)	(1.345–1.626)
	Postseason	1.425 ± 0.07^{a,*}	1.570 ± 0.07^{b,*}	1.552 ± 0.09$^{b,\#}$	1.241 ± 0.09$^{c,\#}$	1.478 ± 0.08$^{a,\&}$
		(1.314–1.560)	(1.479–1.684)	(1.448–1.674)	(1.078–1.363)	(1.342–1.668)
Pelvis BMD (g·cm^{-2})	Off-season	1.385 ± 0.13^{a,*}	1.469 ± 0.12^{a,*}	1.366 ± 0.14^{a,*}	nd	1.432 ± 0.12^{a,*}
		(1.216–1.647)	(1.278–1.638)	(1.210–1.637)	nd	(1.184–1.637)
	Preseason	1.396 ± 0.14^{a,*}	1.474 ± 0.13^{a,*}	1.365 ± 0.16^{a,*}	1.110 ± 0.11^{b,*}	1.453 ± 0.14$^{a,\#}$
		(1.190–1.650)	(1.291–1.671)	(1.194–1.679)	(0.972–1.295)	(1.160–1.651)
	Postseason	1.405 ± 0.14^{a,*}	1.494 ± 0.12$^{a,\#}$	1.371 ± 0.15^{a,*}	1.124 ± 0.11$^{b,\#}$	1.470 ± 0.13$^{a,\#}$
		(1.183–1.652)	(1.335–1.675)	(1.199–1.662)	(0.985–1.326)	(1.184–1.651)
Spine BMD (g·cm^{-2})	Off-season	1.216 ± 0.15 $^{a,*,\#}$	1.356 ± 0.18 $^{a,*,\#}$	1.254 ± 0.10^{a,*}	nd	1.280 ± 0.14^{a,*}
		(0.981–1.507)	(1.093–1.536)	(1.049–1.390)	nd	(0.958–1.498)
	Preseason	1.224 ± 0.18^{a,*}	1.305 ± 0.10^{a,*}	1.360 ± 0.12$^{a,\#}$	1.063 ± 0.13^{b,*}	1.300 ± 0.13$^{a,*,\#}$
		(0.997–1.567)	(1.111–1.446)	(1.141–1.520)	(0.840–1.272)	(0.972–1.553)
	Postseason	1.268 ± 0.15$^{a,\#}$	1.391 ± 0.15$^{a,\#}$	1.336 ± 0.15$^{a,\#}$	1.105 ± 0.13$^{b,\#}$	1.337 ± 0.14$^{a,\#}$
		(1.057–1.637)	(1.195–1.595)	(1.119–1.554)	(0.834–1.337)	(1.001–1.555)
Body fat (%)	Off-season	27.1 ± 5.0^{a,*}	25.5 ± 5.5^{a,*}	27.7 ± 4.1^{a,*}	nd	15.4 ± 4.6^{b,*}
		(18.3–38.4)	(19.5–37.4)	(21.7–33.0)	nd	(9.2–25.9)
	Preseason	25.7 ± 5.0$^{a,b,\#}$	22.7 ± 5.6$^{a,b,\#}$	28.4 ± 4.7^{b,*}	22.5 ± 4.8^{a,*}	14.3 ± 3.9$^{c,\#}$
		(17.1–39.6)	(16.5–35.4)	(19.3–34.1)	(15–31.1)	(8.9–22.2)
	Postseason	25.2 ± 5.7$^{a,\#}$	24.3 ± 5.0^{a,*}#	27.1 ± 5.1^{a,*}	21.9 ± 4.1^{a,*}	15.0 ± 3.9$^{b,\#}$
		(15.8–40.6)	(19.7–35.3)	(18.8–34.3)	(16–29.5)	(8.8–20.9)

[a,b,c] Means ± *SEM* with the same letter(s) across each row (across sports) were not significantly different; $p < 0.05$. *,#,& Means with the same symbols (s) in each column within each sport and variable were not significantly different; $p < 0.05$. Ranges are given in parentheses below the means. Off-season = assessments completed just before the women began preseason physical training; preseason = assessments completed after preseason training and just before the beginning the competitive season; and postseason = assessments made just after the completion of the competitive season. Bone mineral density (BMD) and bone mineral content (BMC). "nd" for swimmers indicates no data available.

softball, basketball, swimming, and track and field during the scholastic year (August–May) of 2006–2007. Unfortunately, no values for swimmers were recorded at the off-season period; therefore, only softball, basketball, volleyball, and track and field data were analyzed for the off-season period. Measurements on volleyball athletes were completed during the 2007–2008 year. Demographics for all athletes are detailed in Table 1.

Statistical Analyses

SPSS for Windows version 15.0 (SPSS, Inc., Chicago, IL) was used to analyze the data. Tests for significant differences between the sports at each seasonal period were performed via analysis of variance (ANOVA) with Tukey post hoc follow-up testing when necessary. Dependent variables of interest included TM, LM, FM, %BF, BMC, BMD, ABMD, LBMD, PBMD, and SBMD. To determine if significant differences occurred within each sport over the seasonal periods, repeated-measures ANOVA with least significant difference (LSD) pairwise post hoc tests were used. The comparisonwise type I error rate was set at $\alpha \leq 0.05$.

RESULTS

The results of comparing all women sport groups at each seasonal period are shown in Table 2. In comparison to the other athletes, track jumpers and sprinters ranged between 14 and 23% less in TM, 50–55% less in FM, and 40–44% less in %BF at the off-season measurement period (Table 2). Basketball and volleyball athletes had the highest TM, LM, and LBMD, with values for basketball women significantly higher than those in softball (+11, +13, and +8%, respectively) and track (+23, +12, and +6%, respectively). Bone mineral density and BMC were significantly higher in basketball compared with softball athletes (BMD, +6%; BMC, +14%), but differences in these 2 variables among basketball, volleyball, and track athletes were not significant. No ABMD, PBMD, and SBMD sport differences were found among the athletes. At preseason (Table 2), all bone measurements in swimmers were significantly less compared with all other athletes ranging as follows: BMC ≤ 10–23%, BMD ≤ 10–15%, ABMD ≤ 6–9%, LBMD ≤ 14–21%, PBMD ≤ 19–25%, and SBMD ≤ 13–19%. Female track athletes had the lowest TM, FM, and %BF values ranging as follows: TM ≤ 10–21%, FM ≤ 42–60%, and %BF ≤ 36–50%. Basketball and volleyball athletes had the highest LM, with values for female basketball players being significantly greater than those of softball players (+13%), swimmers (+11%), and female track athletes (+12%). Respective values for softball athletes fell essentially between the extremes of those recorded for the other sports. At the postcompetition measurement period (Table 2), swimmers again measured the lowest in BMC (≤13–28%), BMD (≤11–17%), LBMD (≤13–21%), PBMD (≤18–25%), and SBMD (≤13–21%), whereas women jumpers and sprinters were lowest in %BF (≤32–45%) and FM (≤37–54%) measures. Total body mass measured significantly higher in basketball athletes compared with swimmers (+14%) and female track athletes (+25%), and LM was significantly higher in basketball players compared with athletes competing in softball (+12%) and track and field (+11%). All significant differences previously mentioned had a calculated effect size ≥1.12.

Significant changes in variables of interest were observed across the season for women in all sports reflecting the influence of training and sport competition (Table 2). When significant changes were noted, they generally occurred in all sports between the off-season and preseason or postseason periods. Only SBMD measured significantly different among the seasonal periods in all sports. Interestingly, changes in many of the bone values did not reach significance until the postseason measurement period.

DISCUSSION

This is the first study to use serial DXA measures to quantify and compare bone and body composition profiles of women collegiate athletes competing in sports with various weight-bearing and muscular power requirements at 3 distinct time periods in their training year: off-season, preseason, and postseason. Our results reflect the physical characteristics of women athletes successful in their chosen sport, the adaptive responses to physical training, and the sport-specific loading characteristics on bone.

The significantly lower BMD in swimmers compared with that in women in other collegiate sports in our study corroborates the findings of previous authors (4,6,13,19). For example, Taaffe et al. (19) compared the effects of swimming with weight-bearing activities and found that although swimmers exert forceful muscular contractions, the absence of high impact loading, as found in sports such as gymnastics, is likely the reason for lower peak BMD in swimmers. This was also observed by Creighton et al. (4) in swimmers compared with basketball and volleyball players. Therefore, our findings of lower BMD in swimmers taken together with similar reports by others suggest that training involving high-impact loading and exposure to high rates of bone strain are crucial for stimulating osteogenesis resulting in heightened bone development (3–6,13,19).

Additional factors related to mechanical loading, have been shown to affect BMD. For example, relationships between TM and LM have been linked to peak BMD values (5). Egan et al. (5) found that women athletes in high-impact sports with greater TM and LM had the highest BMD. This suggests that athletes with greater TM and LM, who are engaged in sports requiring high-impact loading, create greater peak force and greater peak strains on bone, which can result in a greater osteogenic response. However, our track jumpers and sprinters had the lowest TM, yet demonstrated measures of BMD not different from basketball and volleyball players, who had the highest TM. Furthermore, LM in our track athletes averaged between 9 and 14% less than in our basketball players at all 3 measurement periods, yet again their BMD was relatively similar. The lack of differences in BMD we found among basketball, volleyball, and track athletes in our study may be because of the fact that our track and field group comprised jumpers and sprinters. Though we did not measure biomechanical bone loading characteristics in our track athletes, it is reasonable to conclude that they would be comparable to those in basketball and volleyball athletes, because these sports involve similar jumping and sprinting tasks, which might explain similar BMD values despite lower TM and LM in the track athletes.

Recurring differences among the sport participants' body composition at each seasonal period were observed. Our findings of lower FM and %BF in track jumpers and sprinters were to be expected, because to be competitive, it is essential these athletes have relatively low FM and %BF to maximize speed and jumping capabilities (20). Interestingly, LM, %BF, and FM in swimmers were statistically similar to respective values in women participating in the other sports included in our study. This lack of difference implies that swimming can still aid in muscle development and can contribute to maintenance of an appropriate FM and %BF. Furthermore, FM, %BF, and TM were similar among softball, basketball, and volleyball athletes, which suggests a similar body compositional requirement for optimal performance in these sports.

Our body composition values were found to be much higher in comparison to those published previously from studies conducted almost 2 decades ago, and in which only the effects of a competitive season were examined (11,19). Hydrostatic weighing was used in these previous studies to determine bone and body composition and not DXA. Interestingly, because of the emergence of DXA for determining bone and body composition, no longitudinal morphological data in women athletes have been published. Our data are the first to provide DXA-derived reference values, and to compare and contrast bone and body composition measures among women athletes in different sports at 3 separate seasonal periods using DXA. These sport-specific findings will provide coaches and other practitioners with comparative morphological values for collegiate women athletes participating in the sports represented in our study.

It was observed that women softball players exhibited BMD values at off-season that were significantly lower (−7%) in comparison to those of basketball athletes. However, by the preseason measure, no significant differences in BMD were observed. Thus, it appears that preseason training for softball athletes, with an emphasis on resistance exercise training for strength and power, was sufficient to stimulate an increase in BMD. However, by postseason, when the women were engaged in playing the game with little time spent in resistance training, BMD values were again significantly lower (−7%) compared with basketball players. This demonstrates the importance of serial measures of BMD and of other measures of bone mineralization and body composition when drawing conclusions about the effects of sport participation on these variables. Previous authors generally based conclusions on a single measurement period (5,6,13–15), and rarely specified the seasonal period in which their measures were made. For comparison purposes, the period of the training year must be clearly specified in future studies purporting to compare morphologic data among women competing in various sports.

To the authors' knowledge, our data are the first published to quantify the seasonal effects of women's athletic participation on bone and body composition assessed by DXA. The addition of an off-season measurement before preseason training in our study enabled us to assess the effects of "unloading" from training and competition (i.e., detraining), which occurred after cessation of competition in the previous season. We found that significant changes in bone and body composition variables occurred most often between off-season and preseason or postseason. It is natural that athletes would detrain during their off-season because of the absence of carefully coordinated physical training supervised by coaches. Furthermore, the intense physical training of the preseason and of the competitive season would likely induce adaptive increases in bone mineralization and changes in body composition consistent with the training stimulus. Thus, a critical time in preparation for competitive success appears to be the preseason period involving structured and sport-specific physical training to prepare the body for the competitive season.

Interestingly, in the women engaged in the various sports, we studied, increases several regional and total body BMD values did not reach significance until the postseason measurement period. This delayed response could be because of the loading frequency and mechanical loading exposure of bone to the osteogenic stimuli of exercise training. In support of this concept, Hsieh et al. (9) found that increasing the load frequency in adult female rats positively affected the mechanical strains and osteogenesis dose–response relationship in the animals, resulting in greater bone formation. Furthermore, Robling et al. (17) reported that peak bone formation in adult female rats trained 16 weeks occurred when mechanical loading was administered in 4 separate short bouts per day, instead of one long uninterrupted bout of exposure. They concluded that the greatest osteogenic response occurs when long-term mechanical loading is coupled with multiple short bouts of exposure each day. These findings in animals may help explain our results. The competitive season adds to any increases realized during preseason by incorporating a greater duration of exposure to multiple bouts of mechanical loading on most days through a combination of one or more activities: practice, strength training and conditioning, and competitive play. Comparatively, off-season and preseason training sessions are generally shorter in duration, with the primary focus on one intense bout of mechanical loading per day. Additionally, these significant adaptations in BMD have been shown to occur over a longer duration suggesting that the competitive season can also provide the appropriate period of time for increasing BMD (21).

Published %BF values average 20–24% for untrained women 15–19 years of age, and 22–25% for those 20–29 years old (22). The %BF of our basketball athletes (24%) and swimmers (22.2%) was average for their age, whereas those of track athletes (15%) were below, and for women softball (26%) and volleyball players (27%), it was above their age-matched average. It is important to note, however, that the general population norms set for women are generally based upon prediction equations using skinfold measurements (10). Ball et al. (2) reported that the Jackson et al. (10) skinfold prediction equation significantly underestimated %BF by 3.2–5.6% in women scanned by DXA. We are unaware of any other published seasonal body composition data in women athletes measured by DXA to compare with ours. We also know of no published DXA-derived population normative body composition data for women of various ages with which to compare our findings. If we apply a 3.2–5.6% correction in body fat to our DXA data, as suggested by Ball et al. (2), then the percent-fat values for all our women athletes in all sports would be considered at or below the age-matched untrained population average. We suggest that this is an appropriate way to interpret our data.

Attaining a peak bone density during a woman's maturation phase into her early twenties can have profound health implications in the prevention of osteoporosis later in life (16). Because weight-bearing physical activity can promote increases in bone density (3,4,12,13), sport participation by women has the potential to promote healthy bones. The BMD average values of all women in our study, with the exception of those of swimmers, were higher than in sedentary controls measured by Egan et al. (5), with values for softball players being +13%, basketball +20%, volleyball +17%, and for track jumpers and sprinters +17% higher by comparison. Despite swimmers posting LM and average to below average %BF and FM when compared with the other athletes in our study, their BMD was similar to that of a sedentary population. This likely reflects the nature of their sport in which the buoyant force of water reduces bone stress, and therefore the stimulus for increased BMD. Participation in the other sports included in our study seems to contribute to a healthy bone profile in these young women.

In summary, to our knowledge, this is the first study to use serial DXA measures to quantify bone and body composition measurements in women participating in 5 NCAA Division I collegiate sports programs at 3 distinct seasonal periods. Women athletes in our study generally demonstrated sport-specific differences in body and bone composition. Furthermore, many of the variables measured responded appropriately to physical training and sport competition. Thus, it is important that training status be taken into account when comparing women's bone and body composition among sports. In regards to overall health benefits, we found that these women athletes throughout all 3 sport seasonal periods generally posted higher BMD (except for women swimmers), and average to below average %BF values compared with their respective age-matched population.

PRACTICAL APPLICATIONS

For the practitioner involved in coaching and training, these data can serve as sport-specific standards for comparison at off-season, preseason, and postseason training periods among women athletes participating in the sports included in this study. Furthermore, these data can serve as reference values for bone and body compositional changes that accompany training and maturation throughout an athletes' collegiate career. It is important to note that these team results are not position specific and do not account for likely position-specific variations that exist within each sport team. Therefore, applying these values for individual athletes might not be appropriate. Also, these results should only be applied to women collegiate athletes participating in the sports included in this study and is not intended for high-school athletes or other sports.

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