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Side-To-Side Comparisons of Bone Mineral Density in Upper and Lower Limbs of Collegiate Athletes

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Abstract

This cross-sectional study investigated the effects of participation in various sports on side-to-side (contralateral) differences in bone mineral density (BMD) of the upper and lower limbs. The BMD of the arms and legs was measured using dual energy X-ray absorptiometry. The subjects were 184 collegiate athletes, both men and women, who participated in NCAA Division I-A baseball, basketball, football, golf, soccer, tennis, cross-country, indoor/outdoor track, and volleyball. Results revealed greater BMD of the right arms compared with the left arms for all teams, with the most pronounced differences observed in men's and women's tennis and men's baseball. Differences in the lower limbs were less common. No significant differences in lower limb BMD were found in the women. In men, differences in lower limb BMD were found in the football and tennis teams, with the nondominant leg having greater bone mass. Recognition of contralateral differences in bone density may be of particular interest to strength and conditioning professionals as they consider the need to include bilateral and unilateral training programs in an effort to maximize performance and minimize stress-related injuries.

Keywords

site-specific; absorptiometry; contralateral; exercise; mechanical loading; training

Introduction

There is strong evidence that exercise increases bone mineral density (BMD) levels. Both strength-training activities (i.e., high muscle-load activity such as weight lifting) and weight-bearing endurance or aerobic exercise (e.g., running or cross-country skiing) produce these positive effects on BMD. Consistent with theories of mechanical loading and specificity of training, BMD typically is greater in the regions affected by the particular type of exercise. For example, cross-sectional comparisons have found higher BMD in the spine, arms, and legs of competitive weightlifters compared with nonweightlifters matched for age and weight (1, 3). Volleyball and basketball players have higher BMD of the calcaneus and lumbar spine compared with nonathletes (10). In addition, professional tennis players have

higher BMD at several sites, particularly in the dominant forearm, compared with nonathletes (8).

Although cross-sectional comparisons of athletes and nonathletes generally support theories of mechanical loading and specificity of training, several confounders cannot be ruled out using this study design. Specifically, athletes and nonathletes may differ from each other in several respects other than physical activity patterns that may affect bone density, including genetics, hormonal levels, and nutritional status. One way to control for these confounders is to make side-to-side (right vs. left), or contralateral, comparisons of bone mass in the same individuals. If mechanical loading and specificity of training in fact influence the development of bone mass, the limb that receives the greatest loading should have a higher bone mass. To test this hypothesis, Rico et al. (9) compared the dominant and nondominant arms of 50 healthy, sedentary men and women and found increased cortical bone mass in the dominant arm.

Because many sports impose relatively great unilateral loads, sports participation is expected to increase BMD at the skeletal sites that are used the most. For example, participation in sports requiring unilateral use of the arms will likely result in greater bone mass in the dominant arm. Similarly, sports requiring unilateral loading of the legs will likely result in greater bone mass in the dominant leg. Several studies of athletes have supported these site-specific adaptations. Haapasalo et al. (2) found side-to-side differences favoring the dominant arm in female squash players. In a study of baseball pitchers, Watson (11) found the dominant humerus to be significantly more mineralized than the nondominant humerus. Montoye et al. (6) studied senior tennis players and found the width and the bone mineral content of the ulna, radius, and humerus to be significantly greater on the dominant side. Similarly, Jones et al. (4) found significantly greater cortical bone thickness in the dominant limbs of tennis players. Finally, in a study examining side-to-side BMD in young athletic women, Lee et al. (5) found significantly greater right-arm BMD in volleyball, basketball, soccer, and swimming teams and found no differences in leg BMD except in volleyball players, who had greater BMD in the left leg as compared with the right leg.

Strength professionals are trained to provide programs that focus on the enhancement of strength and muscle mass. But recognizing the potential impact of specialized, localized resistance training on bone health is also important. Because previous studies of side-to-side comparisons in athletes have been limited in terms of sample size, gender, and the number of sports teams studied, the purpose of the present study was to investigate side-to-side differences in BMD among a large group of collegiate athletes, both men and women, across 9 different sports with varying loading characteristics.

Methods

Experimental Approach to the Problem

Adopting a cross-sectional design, this study examined side-to-side differences in BMD in college athletes. Two-way repeated-measures analyses of variance were used to assess side-to-side differences in BMD as a function of team. Analyses were conducted separately for men and women because sports teams were not identical across genders (e.g., only male

football players and female volleyball players were assessed). Significant ($p = 0.05$) side-by-team interactions were followed up using analyses of simple main effects (7). To maintain an overall p level of 0.05 across the multiple comparisons made in follow-up testing, familywise Bonferroni corrections were used (7).

Subjects

Subjects in this investigation were NCAA Division I-A athletes (121 men and 63 women) who were involved in strength-training programs designed by team trainers. All teams received both in-season and off-season training prescriptions. A total of 184 athletes (63 women, 121 men) who reported being right-hand dominant were included in analyses of right arm vs. left arm differences in BMD. Among these 184 athletes, 119 (40 women, 79 men) reported also being right-leg dominant and were included in analyses of right leg vs. left leg differences in BMD. Several teams were represented, including men's and women's basketball, golf, tennis, cross-country track, and indoor/outdoor track. In addition, men's baseball, football, and soccer teams, as well as women's volleyball teams, were included. This study was approved by the Institutional Review Board at The University of Memphis.

Bone mineral density was determined by a certified radiology technologist using a Hologic QDR-2000 dual energy X-ray absorptiometer (DEXA) (Hologic, Inc., Waltham, MA; software version V 7.1). Through this analysis, the body may be segmented into regions of interest. Regions of interest analyzed in the present study included the right arm, left arm, right leg, and left leg.

Quality control calibration procedures were performed before each testing session on a spine phantom (Hologic X-CALIBER Model DPA/QDR-1 anthropometric spine phantom). The spine phantom was scanned in the anterior posterior single-beam mode, array mode, and lateral array mode. Test-retest reliability on subjects was measured by conducting serial DEXA scans on 14 athletes; the scans were taken approximately 30 minutes apart, allowing an assessment of intraoperator reliability. The mean deviation for BMD, leg BMD, total body lean tissue, and leg lean tissue averaged 0.31%, and the mean intraclass correlation was 0.985. All scans and analyses were conducted by the same technologist.

Results

Table 1 presents right-arm and left-arm BMD as a function of gender and team. Right-arm vs. left-arm BMD differences varied according to team for both men ($p < 0.0001$) and women ($p = 0.038$). In follow-up analyses, right-arm BMD was significantly greater than left-arm BMD for all men's teams, with differences ranging from 4.4% among basketball players to 17.6% among tennis players. Similarly, right-arm BMD was greater than left-arm BMD for all women's teams, with differences ranging from 6.8% among cross-country track athletes to 16.2% among tennis players.

Right-leg and left-leg BMD as a function of gender and team are presented in Table 2. Side-to-side differences were less pronounced for the legs compared with the arms. For women, no side ($p = 0.302$) or side-by-team ($p = 0.100$) effects were observed. For men, a side-by-team effect was observed ($p = 0.010$). In follow-up analyses, side-to-side differences among

men were significant only for football and tennis players. Right-leg BMD was lower than left-leg BMD for both football (−1.6%) and tennis (−4.0%) players.

Discussion

Examination of side-to-side differences in BMD among athletes is a useful model to further our understanding of mechanical loading processes in bone development. We were able to examine side-to-side BMD differences of the upper and lower limbs in a large group ($N=184$) of collegiate athletes, both men and women, across several sports. Because all the athletes selected for this study were right-arm and right-leg dominant, we anticipated that the right limbs would have greater BMD because of increased mechanical loading at these sites. In addition, we anticipated that the most pronounced side-to-side differences would be observed for sports that require dominant limb involvement in continuous loading activities. Our results generally supported these hypotheses. Bone mineral density was substantially higher in the dominant arm, and this effect was most pronounced for sports that are characterized by unilateral loading (tennis, baseball). Compared with the arms, however, side-to-side differences for the legs were much less consistent.

Bone density of the right arm was greater than that of the left arm for both men and women across all teams, although the magnitude of the difference varied considerably by team. Consistent with the work by Watson (11), Haapasalo et al. (2), Jones et al. (4), and Montoye et al. (6), the greatest side-to-side differences were found for sports that involve asymmetrical loading patterns, including tennis and baseball. Right-arm BMD, compared with left-arm BMD, was 17.6% higher at the right arm for male tennis players, 16.2% higher for female tennis players, and 15.3% higher for male baseball players. Side-to-side differences for other teams, including golf, basketball, volleyball, and cross-country, ranged from 4 to 10% for both men and women. These findings are interesting. Although unilateral loading is not profound in sports such as basketball, volleyball, and golf, the players rely on the dominant arm to execute necessary moves throughout practice and game situations, resulting in continuous increases in exercise stress on the limbs. But because there is very little arm involvement in the sports of soccer and track, these differences are likely attributable to dominant arm involvement in usual and ordinary tasks in addition to the small increases that may have resulted from sports participation. Lee et al. (5) found similar results in young athletic women involved in volleyball, basketball, and soccer, whereas they did not find significant arm differences in swimmers. One must also consider that these teams may have been involved in other activities that require increased dominant-limb loading patterns sufficient to promote BMD development in the arms. Future studies should longitudinally evaluate changes in contralateral BMD as athletes train.

Side-to-side BMD differences for the lower limb were not expected for the majority of sports teams. With the possible exceptions of basketball, volleyball, and tennis, training and performance for the sports studied are thought to rely on cyclical loading patterns and seemingly equal force distribution of the lower extremities. Consistent with our expectations, side-to-side leg BMD differences were not found for any of the women's teams. For men, differences were found only for football and tennis. For both these teams, BMD was greater for the left (nondominant) leg, averaging a 1.6% difference for football

and a 4.0% difference for tennis. These results are consistent with findings by Lee et al. (5), who reported no side-to-side leg BMD differences for female athletes involved with basketball, soccer, and swimming but greater BMD at the left lower limb for volleyball players. Why leg BMD is greater at the nondominant limb among men playing football and tennis is unclear. Forces extraneous to the sports themselves may be responsible for these effects. The difference observed for football (1.6%) is quite small and is unexplainable without more detailed information on positions played and training patterns. The side-to-side difference for male tennis players, however, was substantial (4.0%) and may be explainable by the law of opposition, which suggests that when hitting with the right arm, the left leg will be leading, thereby increasing the magnitude of forces placed on this limb. These possibilities, however, are speculative. Further investigation is needed to explain the possible underlying mechanisms for these differences.

This study supports the theories of mechanical loading and specificity of training, with the dominant arm having greater BMD than the nondominant arm for all teams examined. Studies are needed to further examine the issue of contralateral bone density in a variety of athletic teams as well as in nonathletic populations. Additionally, prospective studies examining changes related to mechanical loading patterns over time would add greatly to this body of literature.

This study makes an important contribution to the literature on bone health by exploring the influence of mechanical loading on bone mass and identifying possible anatomic sites that may benefit from increased unilateral exercise loading. But several limitations to this study should be noted. Although the overall sample size was relatively large, some teams were represented by a small number of participants. Also, because detailed training records were not available, we cannot rule out the possibility that factors unrelated to subjects' sports participation may have contributed to the observed differences. Despite these limitations, the results of the current investigation document side-to-side differences in upper-limb BMD among collegiate athletes, consistent with the theory of mechanical loading, and show that these differences are most pronounced for sports that involve unilateral continuous loading to the upper limbs.

Practical Applications

The results of this study suggest that task-specific bone adaptations result from sports participation. In light of this, strength professionals must recognize the potential positive and negative influences of specific sports and design training programs to counteract any potential negative influences. These findings are important, given the potentially harmful effects of low BMD and the positive adaptations that may occur with specialized, localized training. Such information aids the strength professional in developing exercise prescriptions that will enhance bone status at sites that are most susceptible to stress and fractures, thus possibly preventing debilitating injuries. The results of this study also suggest the possible need for strength professionals to include more unilateral training to optimize bone mass development at all sites. This illuminates the need for strength professionals to consider the effects that unequal force distributions may have on the skeletal integrity of the athlete and to adjust the training program accordingly.

Acknowledgments

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Table 1

Bone mineral density (BMD) of the right and left arms according to gender and team.

	<i>n</i>	Right arm	Left arm	% Difference [*]	<i>p</i> [†]
Male teams					
Baseball	24	0.985	0.858	15.3	<0.0001 [‡]
Basketball	10	0.980	0.940	4.4	0.0130 [‡]
Football	29	1.080	1.030	5.4	<0.0001 [‡]
Golf	10	0.870	0.807	7.8	<0.0001 [‡]
Soccer	22	0.892	0.835	6.8	<0.0001 [‡]
Tennis	6	0.901	0.767	17.6	<0.0001 [‡]
Cross-country track	6	0.830	0.758	9.5	0.0010 [‡]
Indoor/outdoor track	14	0.960	0.897	6.9	<0.0001 [‡]
Female teams					
Basketball	10	0.834	0.775	8.0	<0.0001 [§]
Golf	6	0.741	0.675	9.8	<0.0001 [§]
Tennis	7	0.772	0.665	16.2	<0.0001 [§]
Cross-country track	10	0.737	0.691	6.8	0.0010 [§]
Indoor/outdoor track	18	0.786	0.732	7.6	<0.0001 [§]
Volleyball	12	0.841	0.796	6.0	<0.0001 [§]

^{*} Calculated as $(\text{right-side BMD} - \text{left-side BMD}) / \text{left-side BMD} \times 100$.

[†] Derived from analyses of simple main effects within repeated-measures analyses of variance.

[‡] Statistically significant at a Bonferroni-corrected *p* value of 0.0062.

[§] Statistically significant at a Bonferroni-corrected *p* value of 0.0083.

Table 2

Bone mineral density (BMD) of the right and left legs according to gender and team.

	<i>n</i>	Right leg	Left leg	% Difference [*]	<i>p</i> [†]
Male teams					
Baseball	8	1.345	1.380	-2.5	0.011
Basketball	4	1.748	1.761	-0.5	0.485
Football	22	1.485	1.509	-1.6	0.004 [‡]
Golf	9	1.235	1.243	-0.7	0.514
Soccer	21	1.326	1.331	-0.3	0.553
Tennis	4	1.285	1.339	-4.0	0.0060 [‡]
Cross-country track	4	1.298	1.309	-0.8	0.547
Indoor/outdoor track	7	1.372	1.340	2.5	0.029
Female teams					
Basketball	7	1.330	1.350	-1.5	ns [§]
Golf	5	1.095	1.130	-2.9	ns [§]
Tennis	7	0.117	1.103	1.2	ns [§]
Cross-country track	7	1.113	1.107	0.6	ns [§]
Indoor/outdoor track	8	1.171	1.156	1.4	ns [§]
Volleyball	6	1.325	1.343	-1.3	ns [§]

^{*} Calculated as $(\text{right-side BMD} - \text{left-side BMD}) / \text{left-side BMD} \times 100$.

[†] Derived from analyses of simple main effects within repeated-measures analyses of variance.

[‡] Statistically significant at a Bonferroni-corrected *p* value of 0.0062.

[§] Analyses of simple main effects not performed because of a nonsignificant side-by-team interaction in a repeated-measures analysis of variance.