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Bone Mass in Female Volleyball Players: A Comparison of Total and Regional Bone Mass in Female Volleyball Players and Nonactive Females

H. Alfredson, P. Nordström, R. Lorentzon

Sports Medicine Unit, University Hospital of Umeå, S-90185 Umeå, Sweden

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Abstract. The purpose of this cross-sectional study was to evaluate bone mass in female athletes participating in an impact loading sport (volleyball), and especially to investigate whether any changes in bone mass might be related to the type and magnitude of weightbearing loading and muscle strength. The volleyball group consisted of 13 first division players (age 20.9 ± 3.7 years) training for about 8 hours/week, and the reference group consisted of 13 nonactive females (age 25.0 ± 2.4 years) not participating in any kind of regular or organized sport activity. The groups were matched according to weight and height. Areal bone mineral density (BMD) was measured in total body, head, lumbar spine, femoral neck, Ward's triangle, trochanter, the whole femur, and humerus using dual-energy-X-ray absorptiometry. Isokinetic concentric peak torque of the quadricep and hamstring muscles was measured using an isokinetic dynamometer. Compared with the controls, the volleyball players had a significantly ($P < 0.05$–0.01) higher BMD of the total body (6.1%), lumbar spine (13.2%), femoral neck (15.8%), Ward's triangle (17.9%), trochanter (18.8%), nondominant femur (8.2%), and humerus (dominant 9.5%, nondominant 10.0%), but not of the head and the dominant whole femur. The dominant humerus showed significantly higher BMD than the nondominant humerus in both the volleyball and nonactive group ($P < 0.05$). There was no significant difference in muscle strength of the thigh between the two groups. In the nonactive group, muscle strength in the quadriceps, and especially hamstrings, was correlated to BMD of the adjacent bones (whole femur, hip sites) and also to distant sites (humerus). However, in the volleyball group there were no correlations between muscle strength and BMD of the adjacent bones, but quadricep strength correlated to BMD of the humerus. These results clearly show that young female volleyball players have a high bone mass. The demonstrated high bone mass seems to be related to the type of loading subjected to each BMD site. Muscle strength of the thigh seems to have little impact on BMD in female volleyball players.

Key words: Bone mass — Females — Volleyball — Muscle strength.

Correspondence to: R. Lorentzon

Weightbearing sport activities are associated with high bone mass in lumbar spine, hip, femur, proximal tibia, and calcaneus [1–6] but athletes participating in nonweightbearing sports such as swimming have been shown not to differ [7] or even have lower [8] bone mass in the lumbar spine than nonactive controls. It is obvious that different types of physical activity create different strain demands on the skeletal bones [4, 9]. However, the specific role of physical activity in the enhancement or maintenance of bone mass in humans is still not resolved [10]. To mediate the greatest osteogenic effect it has been suggested that the mechanical loading on a specific bone site should produce high strains in unusual patterns during short periods that are repeated regularly [11–13]. Furthermore, for each individual, it seems that there is a minimum effective strain stimulus to increase bone mass [14].

Previous cross-sectional studies include information about bone mass in young female volleyball players [2, 8, 15, 16] showing a high bone mass in lumbar spine and hip. In a recent study, postmenopausal Japanese female volleyball players were also shown to have a high bone mass in the lumbar spine and proximal femur [17]. In volleyball, high muscular and gravitational forces act on the skeleton during fast changes of directions, starts, stops, and jumping for smashing and blocking. Volleyball produces ground reaction forces 3–6 times the body weight [18] and can be classified as an impact loading activity according to the definition by Grimmston et al. [19].

Studies have demonstrated significant relationships between muscle strength and BMD of the adjacent bones [20, 21], suggesting a potential for muscle strengthening exercises to increase bone mass. However, to our knowledge no study has investigated whether muscle strength in individuals subjected to intense weightbearing loading from physical activity is related to BMD. Relationships have also been demonstrated between muscle strength and BMD in bones at distant sites [22] indicating a more general relationship between muscle strength and BMD.

The aim of this cross-sectional study was to investigate BMD at different sites in female athletes participating in an impact loading sport such as volleyball and in nonactive females, and whether any differences between the groups could be related to the type of loading and muscle strength of the thigh.

Material and Methods

Subjects

The volleyball group consisted of 13 first division female volleyball players, age 20.9 ± 3.7 years (mean ± SD). They had been active in high level volleyball for 4.8 (range 2–9) years, practiced 8 hours/week, 40 weeks/year. During off season they were training with weights 1–2 hours/week and playing beach volleyball during weekends. Six of the 13 players were taking contraceptive pills. All players had regular menses.

The control group consisted of 13 nonactive, female students, age 25.0 ± 2.4 years, recruited through advertisement at the University of Umeå. From those who answered, the control group was selected to match the volleyball group according to weight and height. They were not participating in any kind of regular or organized sport activity, at most walking and short bicycle rides. None of the nonactives were taking contraceptive pills and all had regular menses.

All volleyball players and nonactives were in good health, not smoking, and on no medication known to affect bone metabolism.

Methods

BMD of the head was derived from a total body BMD scan, using a Lunar DPX-L (Lunar Co. WI), dual-energy-X-ray absorptiometer. The accuracy and precision of this method have previously been discussed in detail by others [23, 24]. BMD of the femoral neck, Ward's triangle, and greater trochanter were obtained using the femur software, and lumbar spine was obtained using the lumbar software (L2–L4). Fat mass and lean body mass were obtained from the total body scan. BMD of the whole femur and humerus were obtained from the same total body scan using the region of interest program. In our laboratory, the coefficient of variation (CV) for a total body scan is 0.7% [25] and the CV values for the femur and spine software are about 1.5% and 1%, respectively (unpublished data). To minimize the interobserver variation, all analyses were made by the same investigator. The reliability of the region of interest program was estimated by analyzing the scans of 15 different subjects twice on different days. The mean difference of BMD between the analyses made on day 1 and day 2 was 0.5% for femur and 0.9% for humerus. By scanning one person 10 times during a short period of time, with repositioning between the scans, the CV was estimated to be 2.2%, 2.4%, and 2.6% for the BMD of head, humerus, and femur, respectively.

Isokinetic Muscle Strength

Isokinetic concentric muscle strength of the quadriceps femoris and hamstring muscles was measured in Newton-meters (NM) using a Biodex isokinetic dynamometer (Biodex Co, New York, USA). The subject sat at a 120° hip angle with the lever attached just above the ankle. The dynamometer's axis of rotation was aligned with the knee joint and the angular movement of the knee joint was 90°. During the test, each subject made five maximal repetitions at 90° second and 10 at 225°/second. The rest between change of velocities was approximately 1 minute. The highest peak torque for each velocity was used in the statistical analyses.

Clinical Measurements

Height and weight were measured in stockinged feet and in underwear using standardized equipment. BMI was calculated (weight/height^2).

Statistics

The results are presented as means ± SD. Differences between the groups were calculated using a nonparametric test for independent samples (Mann Whitney). A nonparametric test for paired samples (Wilcoxon) was used to test side differences in the groups. Bivariate correlations were measured using Pearson's coefficient of correlation. The SPSS package for Personal Computer was used for the statistical analyses. A P value less than 0.05 was considered significant.

Table 1. Group characteristics (mean ± SD)

Measurement	Volleyball players (n = 13)	Nonactives (n = 13)
Age (years)	20.9 ± 3.7	25.0 ± 2.4[a]
Height (cm)	174.4 ± 6.8	171.2 ± 4.3
Weight (kg)	68.6 ± 6.9	64.0 ± 7.7
BMI (kg/m^2)	22.7 ± 2.5	21.8 ± 2.3
Body fat (%)	27.1 ± 5.3	26.7 ± 6.3
Lean body mass (kg)	47.5 ± 3.0	44.4 ± 4.6

[a] $P < 0.05$; nonactives greater than volleyball players

Results

Group characteristics are shown in Table 1. There were no significant differences between the groups when comparing weight and height, but the nonactives were significantly ($P < 0.01$) older than the volleyball players.

Total and regional differences in areal BMD (g/cm^2) are shown in Table 2. The volleyball players had significantly higher (6.1%) total body BMD values than the nonactive group ($P < 0.01$). There were no significant differences in BMD of the head between the groups. BMD of the spine was significantly higher (13.2%; $P < 0.01$), at all sites of the proximal femur (neck 15.8%; $P < 0.05$, Wards 17.9%; $P < 0.05$, greater trochanter 18.8%; $P < 0.01$), and in the nondominant femur (8.2%; $P < 0.05$) in the volleyball players. The volleyball players had significantly higher BMD in the dominant (9.5%) and nondominant (10.0%) humerus compared with the nonactives ($P < 0.05$).

Side-to-side differences in BMD of the humerus and femur for the volleyball players and nonactives are shown in Table 2. The dominant humerus in the volleyball players had significantly higher BMD values than the nondominant humerus (4.5%), and the dominant humerus in the nonactive controls had significantly higher BMD values than the nondominant (5%) humerus ($P < 0.05$). There was no significant difference in BMD between the dominant and nondominant whole femur in the volleyball players, but in the nonactive group, the dominant whole femur had a significantly higher BMD ($P < 0.05$).

Isokinetic concentric peak torque at 90°/second and 225°/second of angular velocity in the quadricep and hamstring muscles is shown in Table 3. There were no significant differences in muscle strength between the volleyball players and nonactive controls.

Correlations between bone mass at different sites and muscle strength in the quadricep and hamstring muscles are shown in Table 4A–B. In the volleyball group, there were no correlations between BMD and muscle strength, except for the dominant humerus that was positively correlated to quadricep strength at both velocities. In the nonactive group, hamstring strength correlated with all measured BMD sites except head, and quadricep strength correlated with all measured BMD sites except head, spine, and hip.

Discussion

Investigation of various groups of athletes offers a means of

Table 2. Bone mineral density (g/cm^2), mean ± SD and difference between the groups (%)

Skeletal site	Volleyball players	Nonactives	% difference
Total body	1.21 ± 0.07[b]	1.14 ± 0.07	6.1
Head	2.23 ± 0.10	2.27 ± 0.16	−1.8
Lumbar spine (L1–4)	1.37 ± 0.10[b]	1.21 ± 0.13	13.2
Femoral neck	1.17 ± 0.12[a]	1.01 ± 0.16	15.8
Ward's triangle	1.12 ± 0.14[a]	0.95 ± 0.16	17.9
Trochanter	1.01 ± 0.11[b]	0.85 ± 0.14	18.8
Dominant humerus	1.15 ± 0.11[a,c]	1.05 ± 0.10[d]	9.5
Nondom. humerus	1.10 ± 0.11[a]	1.00 ± 0.10	10.0
Dominant femur	1.45 ± 0.12	1.37 ± 0.13[d]	5.8
Nondom. femur	1.45 ± 0.13[a]	1.34 ± 0.12	8.2

[a] $P < 0.05$; volleyball greater than nonactives
[b] $P < 0.01$; volleyball greater than nonactives
[c] $P < 0.05$; dominant volleyball greater than nondominant volleyball
[d] $P < 0.05$; dominant nonactive greater than nondominant nonactive

Table 3. Isokinetic concentric peak torque (Nm) in the quadricep and hamstring muscles of the dominant leg in the volleyball players and nonactive controls (mean ± SD)

	Volleyball players (n = 13)	Nonactives (n = 13)
Muscle strength (Nm)/second		
Quadriceps 90°	162.7 ± 28.2	156.2 ± 24.6
Quadriceps 225°	107.1 ± 18.4	100.1 ± 14.8
Hamstrings 90°	83.1 ± 8.4	76.2 ± 13.1
Hamstrings 225°	64.0 ± 9.4	59.8 ± 10.2

There were no significant differences in isokinetic peak torque between the groups

exploring the relationship between physical activity and bone mass. The objective of the present study was to compare the bone mass of female volleyball players with nonactive controls, and to evaluate whether any differences could be related to the type of weightbearing loading and muscle strength of the thigh.

There is always a possibility in cross-sectional studies like the present one that the results might be influenced by selection bias, i.e., that generally stronger females with higher bone mass are more prone to participate and be successful in volleyball. To try to exclude this possibility we measured BMD of the head, which is probably not under the influence of weightbearing loading. There was no significant difference in this BMD site between the two groups investigated, indicating a good match with regard to bone mass between the groups. In our study, there is a significant difference in age (the nonactive group is older), but not in weight and length, between the groups. Recently, Teegarden et al. [26] showed that by age 22.1 ± 2.5 years, 99% of peak BMD, and by age 26.2 ± 3.7 years, 99% of peak BMC is attained in women. Therefore, it is not likely that the difference in age between the groups has any significant impact on the significant differences in BMD in our study, especially as we did record a higher bone mass in the younger group. Any ANCOVA adjustment for age would not be correct for biological reasons. Another difference between the groups is that six of the volleyball players were taking contraceptive pills compared with none of the nonactives. The results of the few studies comparing BMD in regularly menstruating young females who are taking contraceptive pills versus not taking contraceptive pills are conflicting. Mazess et al. [27] found no effect of birth control pills on BMD in 20–39-year-old females, whereas Recker et al. [28] found contraceptives to be associated with a greater gain in total bone mass in college-aged women. We found a higher total BMD in the volleyball players compared with the controls, but the differences in BMD at the weightbearing sites such as lumbar spine and hip were much higher. As mentioned above, there was no significant difference in head BMD between the groups. If the use of contraceptives among the six volleyball players would positively affect the bone mass values, we think the effect would reasonably be a general one, including the nonweightbearing head. Therefore, we do not consider the use of contraceptive pills in six of the volleyball players to be a confounder in this study.

The lower extremities of volleyball players are subjected to high muscular and gravitational forces. Landing from jumping, fast changes of direction, and starts and stops produce ground reaction forces 3–6 times the body weight [18]. Animal studies have shown that the amount of strain the bone is subjected to is an important factor in the regulation of bone mass [14]. Lanyon [13] suggests that regularly repeated high strains distributed in unusual patterns during short periods have the greatest osteogenic effect.

In our study, the BMD values of total body, lumbar spine, all sites of the hip, the nondominant femur, and dominant and nondominant humerus were significantly higher in the volleyball players compared with the nonactives. The greatest differences in our investigation were seen in the hip (greater trochanter 18.8%, Wards 17.9%, neck 15.8%) and lumbar spine (13.2%). In the studies by Fehling et al. [2] and Lee et al. [15], the greatest differences in BMD between the volleyball players and nonactive controls were also found in the hip and lumbar spine, and the percentage differences in BMD were about the same as in our study, except for the BMD values at Ward's triangle, which in the study by Lee et al. [15] were lower. High bone mass in the lumbar spine has also been found in postmenopausal, Japanese, female volleyball players [17]. It appears that in volleyball, the loading situations are associated with strains that evoke a great osteogenic stimulus, especially in the hip and lumbar spine. In volleyball, the lumbar spine and the hip will be subjected to ground reaction forces transmitted through the leg and from compressive forces from body weight transmitted through the spine during jumping, fast changes of directions, and starts and stops. The resultant

Table 4A. Correlations between total and regional bone mass (BMD) and isokinetic concentric strength of the quadricep and hamstring muscles in the volleyball players

	BMD (g/cm^2)							
	Tot. body	Spine	Neck	Wards	Troch	Head	Dom. humerus	Dom. femur
Muscle strength (Nm)/second								
Quadriceps 90°	0.449	−0.079	0.531	0.504	0.528	0.358	0.596[a]	0.462
Quadriceps 225°	0.284	−0.197	0.112	0.458	0.501	0.366	0.561[a]	0.350
Hamstrings 90°	0.188	0.076	0.299	0.129	0.264	0.092	0.144	−0.134
Hamstrings 225°	0.357	0.053	0.314	0.180	0.352	0.428	0.125	0.073

Correlation coefficients and *P* values are presented
[a] $P < 0.05$

Table 4B. Correlations between total and regional bone mass (BMD) and isokinetic concentric strength of the quadricep and hamstring muscles in the nonactive controls

	BMD (g/cm^2)							
	Tot. body	Spine	Neck	Wards	Troch	Head	Dom. humerus	Dom. femur
Muscle strength (Nm)/second								
Quadriceps 90°	0.592[a]	0.179	0.308	0.431	0.323	0.318	0.563[a]	0.607[a]
Quadriceps 225°	0.624[a]	0.246	0.372	0.467	0.370	0.421	0.625[a]	0.606[a]
Hamstrings 90°	0.716[b]	0.477	0.682[a]	0.610[a]	0.560[a]	0.435	0.675[a]	0.784[b]
Hamstrings 225°	0.742[b]	0.613[a]	0.712[b]	0.613[a]	0.602[a]	0.438	0.757[b]	0.730[b]

Correlation coefficients and *P* values are presented
[a] $P < 0.05$; [b] $P < 0.01$

strain in the hip and lumbar spine will probably be high and of a varied pattern. When comparing the volleyball players and nonactives, the BMD values showed a much higher percentage difference in the hip than in the whole femur. One plausible explanation might be that the largest part of the whole femur (diaphysis and distal part) is subjected to predominantly compressive forces, whereas the hip (neck, Ward's triangle, and greater trochanter) is subjected to compressive, bending, and shear forces that produce higher strain levels and possibly a higher osteogenic stimulus. In the present study, we found a significant difference in BMD of the nondominant but not the dominant whole femur between the volleyball players and nonactives. In the volleyball group, there was no significant difference between BMD of the dominant and nondominant whole femur, but in the nonactive group the dominant whole femur had a significantly higher BMD. This might be explained by the fact that right-handed volleyball players mechanically take the greatest load on the left leg in jumping activities, which possibly compensates for the side difference seen in the nonactive group. In the study by Lee et al. [15], female volleyball players were found to have significantly higher BMD in the left leg than in the right leg, but nothing is mentioned about what leg was dominant and there were no measurements of the whole femur to allow a comparison with our results.

We found the volleyball players to have a significantly higher BMD of the dominant as well as the nondominant humerus compared with the nonactives, and both groups also had significantly higher BMD values in the dominant humerus compared with the nondominant humerus. The ratio between the BMD values in the dominant and nondominant humerus was about the same in both groups. These results indicate that the difference in BMD of the humerus between the groups is more an expression of a higher general strain level for both arms in the volleyball group, and that the strain levels produced during smashing, blocking, and serving in volleyball seem not to be high enough to preferentially promote bone formation in the dominant arm.

Fehling et al. [2] found no significant BMD differences in the whole arms when comparing female volleyball players and nonactive controls, but did not specifically examine any differences in BMD between the dominant versus the nondominant arm. Lee et al. [15] found a significantly higher BMD of both the dominant and nondominant whole arm in female volleyball players compared with nonactive controls, and they also found a significantly higher BMD in the dominant whole arm in the volleyball players. However, in their study there are no measurements of the humerus to compare with our results. In a study by Kannus et al. [29] it was shown that the bones in the dominant playing arm in female tennis and squash players (age 27.7 ± 11.4 years) had a significantly higher BMC than the nondominant arm, and a study by Haapasalo et al. [30] on female squash players (age 25.4 ± 4.0 years) showed that the dominant playing arm had significantly higher BMD and BMC values than the nondominant arm, with the largest side-to-side differences in the humerus. Furthermore, a study on male and female professional tennis players (18 and 14 years, respectively, of playing experience) showed a significantly thicker humerus on the dominant playing side compared with the nondominant side [31].

Site-specific relationships have been demonstrated between muscle strength and BMD of the adjacent bones [20, 21]. Accordingly, in a study by Madsen et al. [21] quadricep strength has been demonstrated to correlate with BMD of the proximal tibia in women aged 21–78 years, and Hyakutake et al. [20] found quadricep strength to be an independent predictor of femoral BMD in premenopausal women, suggesting that muscle-building exercise may have a potential to elevate BMD in these subjects. Quite recently, we have demonstrated a possible effect of high quadricep muscle strength on areal BMD of the tuberositas tibiae in young boys on a high level of physical activity [25], but to our knowledge no study has investigated the relationship between muscle strength and BMD in female subjects with a high physical activity. In the present study, there was generally a strong relationship between muscle strength of the thigh and most BMD sites investigated in the nonactive group. These results are well in line with the results recently shown in two studies by Nordström et al. [32, 33], where a positive relationship between muscle strength of the thigh and bone mass in boys on a low activity level was demonstrated. As a contrast, among the volleyball players, only quadricep strength predicted humerus BMD significantly. However, the results demonstrate significantly higher BMD at most investigated BMD sites for the volleyball players, although there was no significant difference in muscle strength of the quadricep or hamstring muscles when comparing the investigated groups. These results imply that muscle strength of the thigh in itself is not responsible for the increased BMD at the adjacent hip in the female volleyball players.

In conclusion, it seems that the dynamic loading in versatile directions that evolves when playing volleyball is associated with a higher bone mass in the lumbar spine and hip in young females. The changes are site specific and can theoretically be related to the high and unusual strains created at certain BMD sites when playing volleyball. It seems that muscle strength of the thigh in itself is not of decisive importance in promoting bone mass at the adjacent bones in this group of female volleyball players.

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