

Effects of different sports on bone density and muscle mass in highly trained athletes

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ABSTRACT

ANDREOLI, A., M. MONTELEONE, M. VAN LOAN, L. PROMENZIO, U. TARANTINO, and A. DE LORENZO. Effects of different sports on bone density and muscle mass in highly trained athletes. *Med. Sci. Sports Exerc.*, Vol. 33, No. 4, 2001, pp. 507–511.

Purpose: It is known that participating in sports can have a beneficial effect on bone mass. However, it is not well established which sport is more beneficial for increased bone mineral density (BMD) and appendicular muscle mass (AMM). This study investigated the effects of different high-intensity activities on BMD and AMM in highly trained athletes. **Materials and Methods:** Sixty-two male subjects aged 18–25 yr participated in the study. The sample included judo (J; $N = 21$), karate (K; $N = 14$), and water polo (W; $N = 24$) athletes who all competed at national and international level. Twelve age-matched nonathletic individuals served as the control group (C). All athletes exercised regularly for at least 3 h·d⁻¹, 6 d·wk⁻¹. Segmental, total BMD, and AMM were measured with a dual-energy x-ray (DXA) absorptiometry (Lunar Corp., Madison, WI). DXA analysis also includes bone mineral content (BMC) and fat and lean masses. **Results:** Total BMD_C was significantly lower (mean \pm SD: 1.27 ± 0.06 g·cm⁻², $P < 0.05$) than either judo or karate athletes (total BMD_J (1.4 ± 0.06 g·cm⁻²) and total BMD_K (1.36 ± 0.08 g·cm⁻²)) but not different from the W athletes (total BMD_W (1.31 ± 0.09 g·cm⁻²)). AMM was significantly lower in the C group compared with the three athletic groups ($P < 0.05$). Fat mass was higher in the W versus J and K athletes but not different from the C group ($P < 0.05$). **Conclusions:** This cross-sectional study has shown that athletes, especially those engaged in high-impact sports, have significantly higher total BMD and AMM than controls. These results suggest that the type of sport activity may be an important factor in achieving a high peak bone mass and reducing osteoporosis risk. **Key Words:** JUDO, KARATE, WATER POLO, BONE MINERAL DENSITY, BODY COMPOSITION, DXA

A decrease in physical activity may lead to an increased loss of bone mineral and an increase in the incidence of osteoporotic fractures. Cross-sectional studies show that athletes, especially those who are strength-trained, have greater bone mineral densities than nonathletes, and that strength, muscle mass, and maximal oxygen uptake correlate with bone density (7,12,23).

Longitudinal training studies indicate that strength training and high-impact endurance training increase bone density (2,25). Strain induction, the deformation that occurs in bone under loading, may cause a greater level of formation and an inhibition of resorption within the normal remodeling cycle of bone, or it may cause direct activation of osteoblastic bone formation from the quiescent state (7). Various mechanisms have been proposed for the transformation of mechanical strain into biochemical stimuli to

enhance bone formation (7). The factors associated with the attainment of optimal bone mineral density (BMD) and bone mineral content (BMC) have not been clearly identified. However, four factors that play major roles, are genetics, exercise, hormonal status, and nutrition (8,16,24). Although genetic influence appears to have the greatest impact, exercise, hormones, and nutrition can modify the actual peak bone mass acquired or maintained. In particular, exercise has been associated with higher BMD in a variety of populations (17,21,30); however, recent reports have described negative effects (i.e., reduced bone density) in runners (4). On the other hand, the most effective exercise protocol for reaching and maintaining the highest BMD has not been firmly established. It is controversial as to the benefit of nonweightbearing activities (such as swimming or water polo) on bone development and maintenance and if the effects are similar to those observed with weightbearing sports. There is some indication that weightbearing exercise may be more beneficial for bone health than nonweightbearing activities (11,15,19,29). Furthermore, physical activities have an effect on body composition (BC), especially

0195-9131/01/3304-0507/\$3.00/0

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Received for publication June 2000.

Accepted for publication June 2000.

TABLE 1. Characteristics of the four groups (mean±SD).

	Control	Judo	Karate	Water Polo
<i>N</i>	12	12	14	24
Age (yr)	22.5 ± 3	22.8 ± 2.8	21.5 ± 3.9	22.4 ± 3.2
Weight (kg) ^a	69.9 ± 11.5	74.7 ± 10.1	73.5 ± 8.2	82.3 ± 9.0
Height (cm) ^b	175.6 ± 6.0	173.5 ± 6.1	176.1 ± 7.0	183.3 ± 4.2
BMI (kg·m ⁻²)	22.6 ± 2.8	24.7 ± 2.1	23.6 ± 1.9	24.5 ± 2.1
Lean (kg) ^c	54.6 ± 7.4	63.3 ± 7.2	61.2 ± 7.0	65.6 ± 5.7
AMM (kg) ^c	25.5 ± 3.8	29.9 ± 3.8	29.2 ± 3.6	31.1 ± 2.9
Fat mass (kg) ^d	11.6 ± 5.7	7.5 ± 3.6	8.3 ± 2.6	12.5 ± 4.7

BMI, body mass index; AMM, appendicular muscle mass.

^a $P < 0.05$ W vs K and C.

^b $P < 0.05$ W vs J, K and C.

^c $P < 0.001$ C vs J and W.

^d $P < 0.01$ W vs J and K.

skeletal muscle, which is of interest to sports scientists. Skeletal muscle is the largest nonadipose tissue component at the tissue-system level of the body composition in humans, and it plays an important role in physical activity and many biochemical process (31). Fat-free mass has commonly been used as a surrogate measure of muscle mass but does not always accurately reflect specific changes in muscle mass or differences in muscle mass between individuals. Recent studies (10,26,31,32) have confirmed that dual x-ray absorptiometry (DXA) can be used as a method for estimating total body muscle mass in healthy men and women of different age groups and that DXA can be used for the estimation of appendicular muscle mass (AMM). Therefore, the purpose of our study was to investigate the effects of different high-intensity activities (nonweightbearing and weightbearing activities) on BMD and AMM in male athletes who chronically train in different activities and thus have differing amounts of mechanical loading on the skeleton.

MATERIALS AND METHODS

Subjects. Sixty-two Caucasian male subjects (age range 18–25 yr) were enrolled for the study. The sample included three groups of athletes: judo (J; $N = 12$), karate (K; $N = 14$), and water polo (W; $N = 24$). A fourth group included 12 age-matched nonathletic subjects who served as the control group (C). All athletes competed at national and international level and exercised regularly for at least 3 h·d⁻¹, 6 d·wk⁻¹. The study was carried out according to the Declaration of Helsinki protocol, and written informed consent was obtained from all participants. None was taking medications or drugs that affect bone and muscle metabolism.

Experimental protocol. All measurements were conducted when the subjects were 12 h postprandial, euhydrated, and had not exercised for 24 h.

Anthropometric measurements. Anthropometric measurements were taken according to conventional criteria and measurement procedures (18). Body weight (Wt) and body height (Ht) were measured to the nearest 0.1 kg and 0.5 cm, respectively. Body mass index (BMI) was calculated using the formula: $BMI (kg/m^2) = Wt(kg)/Ht(m)^2$.

Dietary intake assessment. The food intake was assessed by a semiquantitative questionnaire of food fre-

quency proposed and validated for Italian population (13). The questionnaire consists in a set of forms containing the photos of the most common foods and courses typical of the Italian diet, a list of food items, and a series of check boxes for evaluating the frequency of consumption. The filled forms are processed with a personal computer equipped with a software capable of providing the daily food and dish consumption.

Physical activity assessment. Physical activities of control subjects was not adequately assessed because they participated in activities at a gymnasium or sport club 2 or 3 d·wk⁻¹ for a period of 1 h each time. This activity, however, was not on a regular basis and occurred for only a few weeks at a time. Occasionally, control subjects participated in soccer activities once or twice a month but not on a regular basis or in a competitive sport environment.

BMD, BMC, and body composition measurements. Total body and regional measurements of BMD, BMC, fat mass (FM), and lean mass (LM) made using dual-energy x-ray absorptiometry (Lunar Corp., model DPX, Madison, WI, software version 3.6). The scanner was calibrated daily against the standard calibration block supplied by manufacturer to control for possible baseline drift. DXA measures total BMC with a precision (coefficient of variation) of 0.7%. For lean tissue and fat mass, these values were 0.8 and 1.6% for total body, respectively. AMM was calculated as described by Wang et al. (31). Other details of the DXA measurements are given elsewhere (9).

Statistical analysis. The statistical comparisons for the different variables among the four groups were performed by applying a one-way analysis of variance (ANOVA). Bonferroni *post hoc* tests were performed on all significant mean differences. Correlation analyses between BMD and BC were performed. All statistical analyses were carried out with the SPSS statistical package (SPSS Inc., Chicago, IL).

RESULTS

Anthropometric characteristics. The characteristics of the four groups are reported in Table 1. Results are expressed as mean ± SD. Age was not significantly different among the groups. W athletes had a higher body weight ($83.3 ± 9$ kg; $P < 0.05$) compared with K athletes ($73.5 ± 8.7$ kg) and C subjects ($69.9 ± 11$ kg) but were not different

TABLE 2. Dietary intake assessment among controls and athletic groups.

	Control	Judo	Karate	Water Polo
Kcal·d ⁻¹	2015 ± 740*	3500 ± 850	3600 ± 733	3800 ± 815
Carbohydrate (g)	306 ± 119*	559 ± 130	565 ± 120	600 ± 124
Protein (g)	81 ± 24*	120 ± 25	124 ± 26	111 ± 24
Fat (g)	80 ± 20*	106 ± 21	108 ± 23	119 ± 24
Calcium (g)	995 ± 150*	1100 ± 80	1150 ± 75	1059 ± 70

* $P < 0.05$ C vs athletes.

from J. W were also taller compared with all other groups (Table 1). BMI was not significantly different among the groups. Table 2 shows results of food intake, no differences statistically significant were found between athletes groups for nutrients, but J and K athletes had higher consumption of protein than W and C. W had higher consumption of lipid and carbohydrates than J, K, and C. No differences between athletes groups were found for calcium intake. Calories·d⁻¹ were significantly higher in athletes group than C.

Body composition and body density variables.

Lean mass by DXA (bone-free soft tissue) and AMM were significantly lower in the C group versus J and W athletes ($P < 0.05$) but not different from the K group. Fat mass was significantly higher in the W compared with J and K but not different from the C group (Table 1). A significant correlation was found between AMM and all BMD variables, but no significant correlations were observed between fat mass and BMD across the groups (Table 3).

Table 4 presents total and regional BMD results of the four groups. Total body BMD_C was significantly lower ($P < 0.05$) than BMD_J and BMD_K but not significantly different from BMD_W. This latter value was also significantly lower than the values for the other two groups of athletes. BMD_{arms} was significantly different among all groups with the highest value for BMD_{arms} observed in the J athletes. BMD_{legs} was significantly higher in K group compared with values for the C and W groups ($P < 0.05$). The J group was similar to K but different from C and W. BMD_{trunk} was significantly different between C versus J and K and J versus K groups ($P < 0.05$). W group was similar to C but lower than J and K.

Fat_{arms} was higher in W than J and W and K but not than C ($P < 0.05$). Fat_{legs} was higher in W than J and W but not than C ($P < 0.05$). Fat_{trunk} was higher in W than J and K but not versus C ($P < 0.05$). AMM was statistically lower in C compared with all three athletic groups. (Table 1).

DISCUSSION AND CONCLUSIONS

In the present study, we compared three groups of athletes, judo, karate, and water polo, with an age and sex-matched control group. The results show that the athletes had significantly greater BMD and appendicular muscle

mass than the nonathletes of similar age. This finding is similar to those reported by other researchers (19,20,27,28). It has been accepted that weightbearing forms of vigorous exercise are associated with greater levels of BMD (3); however, the potential benefits of nonweightbearing activities, such as swimming, on bone density are controversial (11,22,28,29).

Our findings have shown that all groups of athletes have a higher BMD compared with the control group; in particular, the judo athletes, practicing a high-intensity weight-bearing sport, had higher values compared with the other athletes. Bone density increases at sites of maximum stress (6,33). The physiological mechanisms involved in the response of bone cells to mechanical stress are still unclear. A possible explanation may be that osteocytes acting as mechanoreceptors respond and release chemical factor capable to promoting osteoblast proliferation at the local bone site.

Stress applied to a skeletal segment affects the geometry of the bone, the microarchitecture, and the composition of the matrix (5). The stimulatory effect occurs when the skeleton is subjected to strains exceeding habitual skeletal loads; under these conditions the intensity of load is more important than the duration of the stimulus. Physical activity leads to greater bone density in children and adolescents and, to a minor extent, in adults (5). Weightbearing activities, such as walking, have a greater effect than nonweightbearing activities, such as cycling and swimming, whereas a reduction in mechanical loading, i.e., bed rest or space flight, leads to bone loss (14). It has been previously suggested that the type of physical activity necessary to build and maintain bone density must be weightbearing, in part, because the loss of ambulation or weightlessness results in marked skeletal atrophy. Research conducted on astronauts suggests that a loss of bone mass could be driven by a lack of gravity. Loss of BMC has been documented in individuals with injuries of central nervous system leading to muscle atrophy and in people restricted to bed for long periods of time. Therefore, weightbearing activity has been widely recommended as a possible prophylaxis for age-related bone loss.

The skeleton provides more than just a framework for the body. Bone is a calcified conjunctive tissue sensitive to various mechanical stimuli, mainly to those resulting from

TABLE 3. Correlation coefficients between appendicular muscle mass, Bone parameters, and fat mass among all groups.

	BMD				BMC			
	C	J	K	W	C	J	K	W
AMM	0.69	0.61	0.61	0.64	0.92	0.87	0.74	0.69
Fat mass	0.41	0.51	0.51	0.31	0.58	0.43	0.58	0.51

TABLE 4. Total and regional bone mineral density (BMD), bone mineral content (BMC), in the four groups (mean±SD).

	Control	Judo	Karate	Water Polo
BMD (g·cm ⁻²) ^a	1.27 ± 0.06	1.40 ± 0.06	1.36 ± 0.08	1.31 ± 0.09
BMC (kg) ^b	3.1 ± 0.4	3.84 ± 0.4	3.67 ± 0.5	3.568 ± 0.6
BMDarms (g·cm ⁻²) ^c	1.00 ± 0.07	1.18 ± 0.06	1.07 ± 0.07	1.09 ± 0.07
BMDlegs (g·cm ⁻²) ^d	1.42 ± 0.09	1.55 ± 0.07	1.58 ± 0.12	1.46 ± 0.12
BMDtrunk (g·cm ⁻²) ^e	1.02 ± 0.06	1.19 ± 0.06	1.12 ± 0.08	1.08 ± 0.08

^a $P < 0.05$ C vs J and K; $P < 0.05$ W vs J and K.

^b $P < 0.05$ C vs J, K, and W.

^c $P < 0.05$ all groups.

^d $P < 0.05$ K vs C and W.

^e $P < 0.05$ C vs J and K and J vs K. ($P < 0.05$).

gravity and muscular contractions. Animal and human studies have demonstrated the importance of weightbearing physical activity as well as mechanical loading for maintaining skeletal integrity (1,4). We have shown that muscle mass was higher in athletes and that water polo athletes had highest values. The increased muscle mass in the athletes probably reflects the significant physical training they undergo. The physical training, in turn, might affect BMD and BMC. In this regard, one might expect that the amount of muscle mass might play a role in skeletal maintenance. In the present study, we demonstrated a higher AMM in the athletes compared with the controls. Within the athletic groups, however, W had the highest AMM but a lower total body BMD, an intermediate level of BMD for the arms, legs, and trunk compared with the J and K groups, suggesting that the AMM alone is not entirely responsible for the increased BMD in the athletic individuals. A variety of other factors may be responsible for the differences observed in the present study. For example, differences in dietary intake

might include differences in total energy, calcium, and vitamin D, to name a few. Additionally, environmental factors like previous physical activity as a child, hormonal homeostasis, and genetics all may play a role in the observed differences in this study. To more fully understand the interrelationship among diet, physical activity, and the development and maintenance of peak bone mass, more integrated research is needed. Future studies should previous childhood levels of physical activity, markers of bone metabolism, and, possibly, the inclusion of parents and siblings together in research studies. In conclusion 1) physical activity appears to have a beneficial effect on bone mass, 2) physical activity with greater mechanical loading appears to result in a greater bone mass than nonweightbearing activities, and 3) there appears to be a site-specific skeletal response to the type of loading at each BMD site.

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