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Effects of unilateral activity on bone mineral density and content in adolescent males

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Abstract

The effects of an unilateral sport, badminton, on radial bone mineral density (BMD) and content (BMC) in adolescent males were examined by dual energy X-ray absorptiometry (DXA). Subjects were all junior high school students, and composed of nine badminton players (Group B; mean age 14.2 years), who had practiced regularly for 2.5 years on the average, and ten control subjects (Group C; mean age 13.9 years) without regular physical activity. All subject had the dominance in the right arm. DXA measurements were done at distal radius and radial shaft for both arms. In group B, the BMC_S and the BMD_S were significantly higher in the playing extremity in both radial sites measured (BMC_S; $p<0.01$, BMD_S; $p<0.05$). On the other hand, side-to-side differences were not significant in the group C at any measured site. Also there were no significant differences between the groups for non-dominant arms. Thus, physical exercise may not have a generalized effect on the skeleton, but may increase the BMC and BMD locally in the exercised limb. It has been concluded that physical exercise increase bone mass in use-dependent manner, so the style of exercise must be carefully considered for mobilizing the bone needed to increase its mass in adolescence.

Footnotes

* The bone tissue area in the DXA measurements was an area which was surrounded by a 10.4 mm longitudinal length of bone and a transverse bone width, so bone tissue area was determined by bone width.

Key words : adolescence, unilateral sport, badminton, DXA, peak bone mass

Introduction

During the adolescent growth spurt in both sexes, an increase in cortical porosity occurs as a consequence of an increase in intracortical bone turnover (remodeling), which is thought to be one of causes for the large increase in incidence of upper extremity (particularly lower forearm) fractures[28]. Also recent studies[2,10,11,24] reported that Ward's triangle or lumber vertebra, which mainly are composed of spongy bone but not of cortical bone[9,23,38], reached peak bone mass by the latter half of the teenage years, implying that prevention of osteoporosis depends on establishing adequate peak bone mass in the

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first two decades of life[23]. These findings emphasize the significance of wide enforcement of bone mass measurement and the establishment of means to increase bone mass in adolescence.

Bone mass is decided fundamentally by a hereditary factor, but also affected by many environmental factors, such as nourishment, smoking habits, drinking, and physical activity levels. In particular, as known well by Wolffs law[39], the bone mass and structure change as mechanical stress is applied to a bone. Accordingly, exercise has become the center of wide interest as a means to apply mechanical stress on a bone. In fact, there are many reports supporting anabolic action of exercise on bone mineral[1,3-5,14,27,33,34,36].

It has been pointed out that growing bone is more sensitive to environmental factors, such as mechanical stress, than an adult bone[30]. When the same exercise program was given to either immature or mature rats, morphological adaptation was observed on the bone of immature rats, but such change was not noticed on that of mature ones[37]. This fact suggests the importance of exercise in adolescence. Nevertheless, the reports[5,12,35] that examined the effects of exercise on skeletal development in adolescence about humans are few.

It has been reported that physical exercise influences serum concentration of many systemic factors such as sex hormone and growth hormone which known to support growth spurt in adolescence[15,16,25,31]. Therefore it is hypothesized that exercise may exert generalized effect even on non-used bones through these factors in addition to mechanical stress. To clarify the expected effects of exercise, we used unilateral sport's players as subject and had two comparisons in the present study. The side-to-side difference that can be seen in the same individual of a unilateral sport's player[13,15,17,20,29] indicates the local effect of exercise, and the generalized effect is estimated as the difference of nondominant limbs between control subjects and unilateral sport players.

The purpose of this experiment was to examine the influence that adolescent unilateral exercise gives to the quantity of cortical bone and trabecular bones.

Materials and methods

Subject

Two groups of nineteen junior high school students, aged 13-15 years were examined in this study. Written informed consent was obtained before the study and a medical questionnaire was administered to identify conditions and medications that might influence the results. Group C was the reference group, consisting of ten healthy students practicing no particular exercise program or sports. Group B was comprised of nine badminton players, who had practiced the sport an average of 2.6 h each day, 6 days/week since they entered the school.

Percent body fat

Skinfold thickness (mm) were measured at the triceps, suprailiac, and abdoments sites using a caliper. Percent body fat was estimated from skinfolds using the Nagamine and Suzuki equation[26].

Bone mineral content and bone mineral density.

Bone mineral content (BMC) and density (BMD) in two sites of radius of both arms were estimated by Dual Energy X-ray Absorptiometry (DXA), using a QDR 1000 (Hologic Corp.) according to a previous study[33]. The measurement sites of radius were the proximal site (radial shaft), one-third the distance from the ulnar styloid process to the olecranon, and the distal site (distal radius), the distal epiphysis near the styloid apophysis. The DXA measurements expressed mineral mass in grams for a 10.4 mm longitudinal length of bone to give the bone mineral content in grams per centimeter. BMD was estimated as areal bone mineral density, mineral content per a certain bone tissue area (g/cm^2).

Statistical analyses

Differences between the groups in all descriptive measurements were evaluated using a Student's *t* test, taking $P < 0.05$ as significant. Comparisons of radial BMC and BMD between dominant and nondominant arms were tested for significance using a paired *t*-test, and P values less than 0.05 were considered to be significant. Pearson's coefficient of correlation was used to determine the relation between the BMC and the bone tissue area.

Results

Physical characteristics

The physical characteristics of the subjects by group are given in **Table 1.** There were no significant differences between the groups in age, height, body weight, % body fat, body mass index (BMI). The exercise history of group B was 2.5 years.

Table 1. Profile of the subjects

Groups (N)	C (10)	B (9)
Age (yr.)	13.9 ± 0.3	14.2 ± 0.6
Height (cm)	162.3 ± 5.4	166.2 ± 6.9
Weight (kg)	46.2 ± 5.4	51.6 ± 7.3
% Fat	11.3 ± 1.9	10.4 ± 1.9
BMI	17.5 ± 1.8	19.0 ± 1.9
Years exercise		2.5 ± 0.5

Values are mean ± S.D.

BMC and BMD

The average bone mineral contents of radius for each group are given in **Table 2.** In group B, the BMCs and the BMDs were significantly higher in the playing extremity in both radial sites measured (BMCs; $p < 0.01$, BMDs; $p < 0.05$). The side-to-side differences were larger in the distal site (BMC 35.2%, BMDs 20.4%) and smaller in the radial shaft (BMC 11.8%, BMD 4.9%). On the other hand, side-to-side differences were not significant in group C at any measured sites.

As for the dominant (right) radius, the BMCs of group B were significantly higher than that of group C at both the distal site (39.8%, $p < 0.01$) and the radial shaft (21.8%, $p < 0.05$). In contrast, BMDs were not significantly different between the groups at both measured sites.

There were no significant differences between the groups in BMC and BMD at any of the measurement sites for the nondominant (left) radius.

Table 2. Radius bone mineral content and bone mineral density in badminton players and nonathletic controls.

Groups (N)	C (10)			B (9)		
	dominant (right) arm	nondominant(left)arm	Diff,%[1]	dominant (right) arm	nondominant(left)arm	Diff,%[1]
Distal radius						
BMC (g)	0.505 ± 0.159	0.468 ± 0.156	7.9%	0.706 ± 0.085 (39.8 %)**	0.522 ± 0.172 (11.5 %)	35.2%##
Area (cm^2)	1.602 ± 0.460	1.450 ± 0.524	10.5%	1.979 ± 0.200 (23.5 %)	1.786 ± 0.567 (23.2 %)	10.8%
BMD (g/cm^2)	0.334 ± 0.090	0.317 ± 0.066	5.4%	0.359 ± 0.034 (7.4 %)	0.298 ± 0.063 (-6.0 %)	20.4%#
Radial shaft						
BMC (g)	0.776 ± 0.109	0.761 ± 0.104	2.0%	0.945 ± 0.142 (21.8 %)*	0.845 ± 0.115 (11 %)	11.8%##
Area (cm^2)	1.176 ± 0.114	1.181 ± 0.104	-0.4%	1.420 ± 0.143 (20.7 %)	1.343 ± 0.124 (13.7 %)	5.7%
BMD (g/cm^2)	0.659 ± 0.060	0.644 ± 0.064	2.3%	0.663 ± 0.050 (0.6 %)	0.632 ± 0.041 (1.9 %)	4.9%#

Values are mean ± S. D.

[1] Diff.%=(dominant - nondominant) / nondominant X 100%

: $p<0.05$, ## : $p<0.01$ vs dominant arm

Differences between group C and group B are shown in parenthesis as percentage to group C.

* : $p< 0.05$, ** : $p<0.01$ vs group C

Correlation between BMC and areal BMD

The relationship between BMD, bone area and BMC at the same measurement site is depicted in **Fig. 1.** As for the radial shaft, the bone area of group B had the strongest correlation with the BMC in either dominant or nondominant extremi-

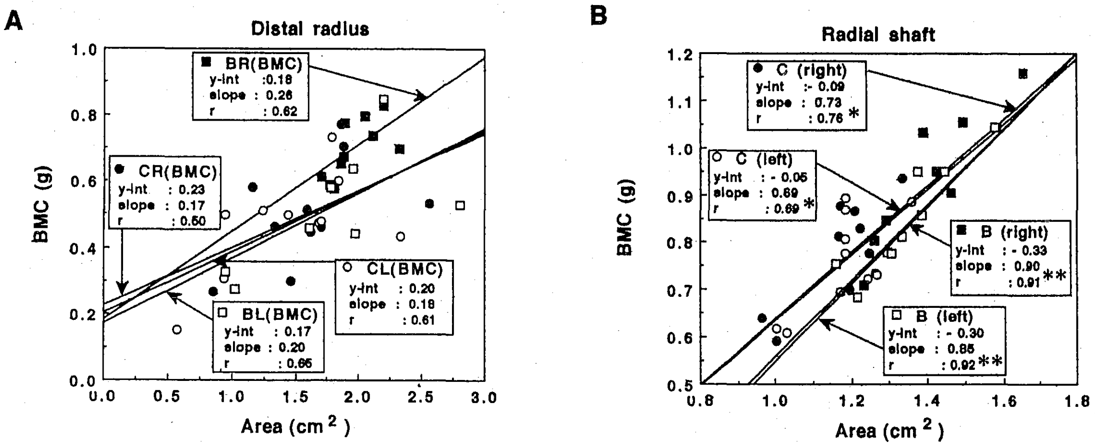

Fig. 1 Correlations between the BMC and the bone tissue area at distal radius (A) and at radial shaft (B). $^{*}p<0.05$, $^{**}p<0.01$

ties (dominant; $r=0.91$, $p<0.01$, nondominant; $r=0.92$, $p<0.01$). Such a relationship between the bone area and the BMC was observed in group C (dominant; $r=0.76$, $p<0.05$, nondominant; $r=0.69$, $p<0.05$).

Although the distal radius showed a similar tendency to the radial shaft for the relationship between the bone area and the BMC ($r = 0.50$-0.65), it was not statistically significant in any group.

Discussion

The present study was the first report that examined the effect of unilateral sport, badminton, on the growing skeleton of adolescent males, and showed that unilateral sport caused significant increases in BMC and BMD in the playing extremity. As for group B, the side-to-side differences in BMC and BMD were 35.2% and 20.4% in distal radius, and 11.8% and 4.9% in radial shaft, respectively. In contrast, the predominance of the more active arm does not appear statistically significant in the nonathletic student group (group C). Since the non-playing extremity of group B did not show significantly higher values in BMC and BMD, compared to group C, it seems unlikely that the higher BMCs and BMDs of badminton players could be caused by a positive selection to the sport. Thus, even during puberty, physical exercise may not have a generalized effect on the skeleton, but may increase the BMC and BMD locally in the exercised limb, in accordance with other studies for adults[4,14,33].

There were some previous studies that examined adults or young adults who participated in unilateral sports[13,15,20,29]. Pirnay et al.[29] reported that on the distal radius of male professional tennis players (mean age 20.3 years), mean BMCs and BMDs of playing extremity were significantly higher than a non-playing extremity by 34% and 12%, respectively. Also, Haapasalo et al.[13] observed in female Finnish national level squash players (mean age 25.4), that side-to-side differences of BMC and BMD in distal radius were 12.4% and 10.0%, respectively. Thus, the degree of side-to-side difference in our badminton players, who were neither professional players nor national level athletes, was as much as in Pirnay's players[29], and was higher than Haapasalo's players[13]. This is a very interesting finding. The great side-to-side difference in this study may be explained by several points, including age of subjects or mode of exercise as described below.

The subject's age is the important factor which influences the effect of exercise. Steinberg and Trueta[37] reported that the growing bone caused morphological changes in response to training with a treadmill, but not the adult bone to the same training. This suggests that the responsiveness of bone to environmental factors such as exercise varies by maturity of bone. Our subjects had started to play badminton since they were 12-years-old, so it is almost equal with Pirnay's subjects[29] who played between the ages of 12-15, and earlier than Haapasalo's subjects[13] of which the mean starting age of active playing was 17.2 years (range 11-25). Thus, the starting age of exercise seems to be related with the degree of its effects on bone mass.

Mechanical stress on bone by external forces in exercise is the important factor which greatly influences bone mass[7,8]. The wrist usage is peculiar to badminton among sports using rackets. The fundamental movements of the arm in a stroke of badminton are pronation and supination. Simkin et al. [34]showed that BMC and BMD at distal radius were increased by loading the forearm in several modes: tension, compression, torsion, and bending in various planes. So, the pronation and supination movements of forearm in playing badminton let a radius sag at every direction, and it might act as the most suitable stimulation for increasing bone mass.

During childhood and adolescence, bone size increases in longitudinal and transverse dimensions. Since the radial diaphysis contains about 90% compact cortical bone, the periosteal or the endo- steal mineral apposition is thought to be the only way to expand cortical bone. In group C, radial shaft BMC was significantly correlated with bone tissue area (bone width) *, as shown in Fig. 1 B. This is in accordance with phenomenon[6] observed in normal growth under which the transverse diameter of diaphysis of the long bones increases by subperiosteal appositional growth which is usually followed by expansion of the marrow cavity. Thus, periosteal mineral apposition is associated with radial shaft BMC in adolescence. It should be emphasized that the strong correlation between radial shaft BMC and bone tissue area was observed in group B, regardless of arm dominance. Moreover, the two regression lines for group B was extremely similar to each other for the slope and y-int. This suggests that a unilateral sport-induced, site-specific increase in BMC results, at least in part from facilitation of normal subperiosteal appositional growth, while another possibility that the contribution of an increased endosteal mineral apposition can not be ruled out.

Previous animal studies[19,20,27] showed that diaphysis of growing bones responded to exercise and mechanical overload by increases in cortical area and BMC due to facilitation of periosteal bone formation. In contrast, exposure of growing bone to zero gravity by space flight caused adverse repression of normal subperiosteal bone formation[40]. Therefore, it seems likely that immature bone, regardless of species, responds to mechanical stress by regulating bone formative cells on periosteum.

The effect of unilateral sport was more conspicuous in distal radius than in radial shaft, indicating a site-specific bone response. It can be explained from at least two points. First, it may be due to the difference of mechanical stress caused in bone in a stroke action. Second, it would depend on the composition of compact and trabecular bones. For radius, the distal epiphysis near the styloid apophysis is composed of about 75% trabecular and 25% compact bone. The radial diaphysis consists of 90% compact cortical bone, as described above. Therefore, the bone surface on which mineral can deposit is much greater at distal radius than at radial shaft. As shown in Fig. 1A, the significant correlation was not observed between BMC and bone tissue area in any group. It might be associated with the fact that trabecular bone mass can change and not be followed by any change in bone tissue area surrounded by cortical bone. It should be noted that the slope of the regression line for the dominant arm was greater than the non-dominant arm in group B, while Group C's two regression lines showed similar slope and y-int to each other. Therefore, the unilateral sport-induced increase in BMC at distal radius can not be explained only by an increase in bone tissue area, implying a contribution of increasing trabecular bone mass and facilitation of subperiosteal bone growth.

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