Research Paper : Fitness and Physical Activities

Childhood Sports Activity Induces Bone Strength in Young Premenopausal Women

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The purpose of the present study was to analyze the beneficial effects of previous sports activity during growth on dual energy X-ray absorptiometry (DXA)-measured mineral content (BMC), bone area and areal bone mineral density (aBMD). We examined whether starting age of sports during childhood induces any changes in DXA-measured bone strength parameters. One hundred and eighteen young women were classified into three groups according to the starting age of sport; an elementary school group, a junior high school–college group and no participation or swimming. The elementary school group showed significantly greater DXA-measured total proximal femur bone area and BMC than no sports groups. However, the elementary school group did not show significantly greater aBMD in total proximal femur and lumbar spine. The junior high school-college group showed significantly greater total proximal femur aBMD than no sports group, while significantly smaller bone area than elementary school group.

Longer duration of past weight-bearing sports participation and higher impact sports activities are more effective for strengthening proximal femur. Weight-bearing exercise in youth affects bone, and the periods before and in early puberty may see sensitive adaptations in structure, shape and size in response to weight-bearing activities. These effects enlarge periosteal surfaces on cortical bone, and the benefits of sports activity during childhood remain, particularly in terms of bone geometry.

Keywords: weight-bearing exercise, bone geometry, DXA, childhood

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1. Introduction

High-impact, weight-bearing exercise during child- (Johannsen et al. 2003; MaKey et al. 2005) to young adulthood (Bassey et al. 1994, Kato et al. 2006) has been shown to increase peak bone mass and may have long-lasting benefits on bone health in later life. After menopause, decreasing estrogen concentrations leads to a decline in bone strength due to the reduction of the bone mineral density. The risk of osteoporotic fractures increase, and weight-bearing activity is thought to be beneficial for reducing the fracture risk. A major strategy to prevent osteoporosis is peak bone mass development during childhood to young adulthood (Kohrt et al. 2004).

In pre-pubertal girls, significant differences in total body and hip areal bone mineral density (aBMD) were observed after 6 months of high-impact exercise intervention (Scerpella et al. 2003). Volleyball and gymnastics athletes aged around 20 years showed a significantly higher aBMD in the lumbar spine (L1-4), femoral neck, and total body than the control and athletes involved in low-impact sports such as swimming (Fehling et al. 1995). Retired professional football players (< 70 yr) had a higher aBMD at loaded sites than age-matched controls (Uzunca et al. 2005). Weight-bearing physical activity involving high-impact movements such as jumping and running has been recommended in children and adolescents to promote their bone health (Kohrt et al. 2004).

In animal studies, not all exercises are equally effective at eliciting an osteogenic response, weight-bearing intermittent dynamic activities which impart high-level strain at a high rate on bones, appear to be the most effective (Lanyon and Rubin 1984; Robling et al. 2000; Robling et al. 2002; Rubin et al. 1984; Rubin et al. 1984; Umemura et al. 1995). Another animal study reported that exercise when young may provide lifelong benefits regarding bone structure and strength, and consequently reduce the fracture risk

(Warden et al. 2007).

The aim of this investigation was to analyze dual-energy X-ray absorptiometry (DXA) measured bone mineral content (BMC), bone area and aBMD in pre-menopausal young women, and access whether past weight-bearing sport activities have a positive effect on BMC, bone area and aBMD. We also focused on whether estrogen function on bone size and stricture affects inducing any changes by childhood exercise in DXA-measured bone parameters.

2. Methods

2.1. Subjects

Subjects comprised 118 young healthy pre-menopausal women (mean age, 21.0±0.7 years, mean height 158.2±4.9cm, mean weight 50.5±6.0kg, and mean age of menarche 12.7±1.6 years). Subjects completed a questionnaire regarding current and past (at elementary school, i.e., 6-12 years old, at junior high school, i.e., 13-15 years old, at high school, i.e., 16-18 years old and at college, i.e., 19-current) physical activity (name of sports, duration (years) and frequency (times/week)), smoking habit, and background information including history of bone disease, medication use and bone fracture. Information on the menstrual cycle was ascertained via in different questionnaire. The subjects reported irregularity of menstrual cycle as oligomenorrhea, if the number of menses in the previous 12 months were fewer than 9 menstrual cycles per year. Inclusion criteria for subjects were: non-pregnant; non-smoker; and no medical or surgical problems likely to affect bone metabolism or contraindicate exercise.

Pre-menopausal subjects were classified into three groups according to starting age of previous sport participation, started from elementary school group, started from junior high school group to college group: such as gymnastics, rhythmic gymnastics, ballet, baton twirling, volleyball, basketball, tennis, table tennis, badminton, football, futsal, softball, karate and shorinji-kempo; and low-impact non-weight-bearing sports swimming or no sports participation, namely no sports group. Sports type was categorized as high-impact weight-bearing sports activities involving jumping movements (e.g., volleyball, basketball, handball, gymnastics and ballet), odd sports activities involving sprint and turning types of sports (e.g., athletics sprint, football, futsal and tennis) and other sports (jogging, marshal arts) and none impact sports such as swimming. Osteogenic index (OI) of previous sport activity was calculated as follows; (times/week) × years × strain score of previous sport activity (Nilsson et al 2009).

The experimental protocol was approved by the ethics committee at the Suzuka University of Medical Science. In compliance with the institutional review board policy, the purposes and all experimental procedures were explained, and written informed consent was then obtained from each subject. Subjects were permitted to withdraw from the study at any time for any reason.

2.2. DXA measurement

BMC (g), bone area (cm^2) and aBMD (g/cm^2) were assessed using DXA (DCS-3000; ALOKA, Tokyo, Japan) of the lumbar spine (L2-4, anteroposterior view) and left total proximal femur. Two dimensional bone area is identified and evaluating the bone geometry as a size of measured bone sites in cm^2. If the same aBMD showed, lager bone area would indicate greater bone strength in terms of bone structure. The coefficient of variation of aBMD measurement displayed an in-house precision error of 1.0% based on adult scans. Short-term coefficients of variation of bone area of post-menopausal women, BMC and aBMD measurements were 2.3%, 2.4% and 0.9% for the lumbar spine (n=8), 1.8%, 1.8% and 0.9% for total proximal femur (TPF), respectively. We did not estimate the coefficient of variation of the DXA measurements for pre-menopausal female college students because of the increased X-ray exposure to the young subjects (20-23 yr). The DXA machine was calibrated daily using a phantom calibration procedure and no significant drift was apparent during the study.

2.3. Dietary calcium intake

All subjects completed consecutive 3-day food records, including 2 weekdays and 1 weekend day. Daily diet records consisted of pictures taken by digital camera and written records of menus and ingredients with approximate weights. Diets were analyzed using Eiyokun version 3.0 software (Kenpakusha, Tokyo, Japan) based on a standard food database by researchers experienced with weighted food records.

2.4. Maximum vertical jump measurement

The maximum vertical jump height was measured by a jump height-measuring device (Takei Scientific Instruments Co., Ltd., Jump-MD, Japan) on the day of DXA measurements. At the visit for measuring jump height, subjects jumped vertically at least twice with maximum voluntary effort, and the best performance was recorded. The subjects stood at the center of the circular thin rubber mat (38 cm in diameter). The jumper attached the height-measuring device to her waist. The jump height-measuring device and a circular mat were attached by a rope so that the travelling distance from the standing position to the maximum height reached at waist level could be measured. When the jumpers could not land stably within the circular rubber mat, they had to perform another trial.

2.5. Accelerometry-determined measures of physical activity

The subjects were asked to attach the accelerometer motion sensor (Suzuken, Lifecorder EX, Japan) at waist height for a whole week except while sleeping or bathing. The physical activity measurements were done during September to October. Movement count values, recorded as steps, were stored every two minutes. The stored data in the accelerometer motion sensor were downloaded by personal computer using a USB cable for analysis.

2.6. Statistics

Mean physiological characteristics, calcium intake, vertical jump height, steps, total past weight-bearing sports activity duration, past high-impact sports participation, and osteogenic index were compared among the three groups classified by starting age of sports; elementary school, junior high school-college and no sports groups using the one-way analysis of covariance (ANOVA). Past weight-bearing sports activity duration, and past high-impact sports duration were tested by unpaired student t-test. And also, χ^2 test was done for number of oligomenorrhea (%) (**Table 1**).

The partial correlations were evaluated between various bone strength parameters and daily calcium intakes, maximum vertical jump height, movement count shown as steps per day, OI and menstrual irregularity with control for height and weight (**Table 2**). Statistical analysis was performed via programs available in version 15.0J of the Statistical Package for the Social Sciences (SPSS, Chicago, USA). Analysis of covariance (ANCOVA) was used to compare significant differences in DXA-measured BMC, bone area and aBMD (**Figure 1 and 2**) between groups without the effects of height and weight. The significance level was set at 0.05, and all comparisons were two-tailed.

Table 1 Physical characteristics, calcium intake, vertical jump height, movement count, sports participated duration and number of oligomenorrhea of 3 groups.

	Elementary school (n=29)	Junior high school (58) High school (6) College (3) (n=67)	No sports (n=22)
Age (yr)	21.2 ± 0.7	20.9 ± 0.6	20.9 ± 0.6
Height (cm)	158.5 ± 4.7	157.6 ± 5.1	159.8 ± 3.9
Weight (kg)	50.0 ± 6.3	50.4 ± 6.1	51.0 ± 6.2
BMI	19.8 ± 1.8	20.4 ± 2.5	20.0 ± 2.5
Calcium (mg/day)	500.5 ± 331.9	441.6 ± 239.7	431.7 ± 160.2
Vertical jump (cm)	41.6 ± 6.4 †	40.8 ± 5.8 †	36.4 ± 5.0
Movement count (steps/day)	7760.0 ± 2316.0	7602.6 ± 2189.9	6526.1 ± 2768.9
Duration of past weight-bearing sports participation (yr)	6.2 ± 2.8 ‡	4.6 ± 2.8	0
Osteogenic index	65.3 ± 48.8 ‡	38.5 ± 21.0	0
Number of oligomenorrhea	6 (20.7%)	22 (32.8%)	7 (31.8%)

Values are means ±SD.
† shows the significant difference vs. No sports group ($p<0.05$).
‡ shows the significant difference vs. Junior high-college group ($p<0.01$).
Body Mass Index

Table 2 Partial correlation between lumbar spine, total proximal femur BMC, bone area and aBMD and calcium intake, vertical jump height, movement count, osteogenic index and menstrual cycle irregularity with control for height and weight.

Variables	Lumbar spine						Total proximal femur					
	BMC		Bone area		aBMD		BMC		Bone area		aBMD	
	Correlation coefficient	*p* value	Correlation coefficient	*p* value	Correlation coefficient	*p* value	Correlation coefficient	*p* value	Correlation coefficient	*p* value	Correlation coefficient	*p* value
Calcium (mg)	−0.123	0.187	0.036	0.705	−0.195†	0.035	−0.010	0.912	0.073	0.439	−0.107	0.253
Vertical jump (cm)	−0.069	0.461	0.125	0.180	0.177	0.057	0.428 ‡	<0.001	0.313 ‡	0.001	0.312 ‡	0.001
Movement count (steps/day)	−0.139	0.137	−0.010	0.916	−0.156	0.094	0.134	0.151	0.176	0.059	0.036	0.705
Duration of past weight-bearing sports participation (yr)	0.036	0.704	−0.018	0.846	0.081	0.390	0.431 ‡	< 0.001	0.383 ‡	<0.001	0.269 ‡	0.004
Osteogenic index	0.047	0.613	−0.059	0.529	0.098	0.293	0.240 ‡	0.009	0.157	0.092	0.278 ‡	0.002
Menstrual cycle irregularity	−0.205 †	0.033	−0.152	0.104	−0.198 †	0.033	−0.017	0.852	0.051	0.588	−0.157	0.092

† shows the significant correlation with DXA-measured BMC, bone area and aBMD at lumbar spine and total proximal femur (p<0.05) and ‡ shows (p<0.01).
BMC (Bone Mineral Contents)
aBMD (areal Bone Mineral Density)

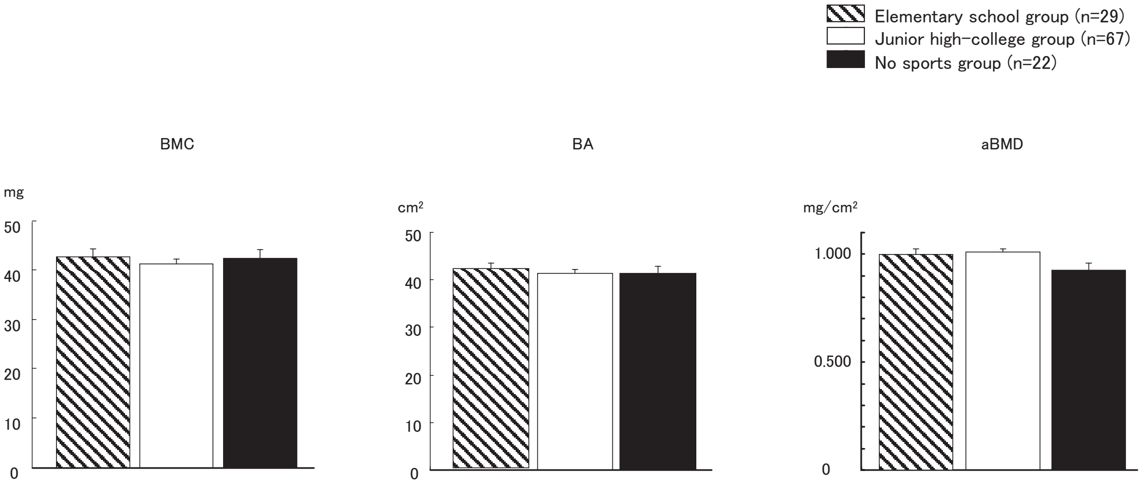

Figure 1 DXA-measured BMC, bone area and aBMD at Lumbar spine (n=118).
Values are means±SEM and adjusted for covariate values of height=158.3cm and weight=49.1kg.
BMC (Bone Mineral Content)
BA (Bone Area)
aBMD (areal Bone Mineral Density)

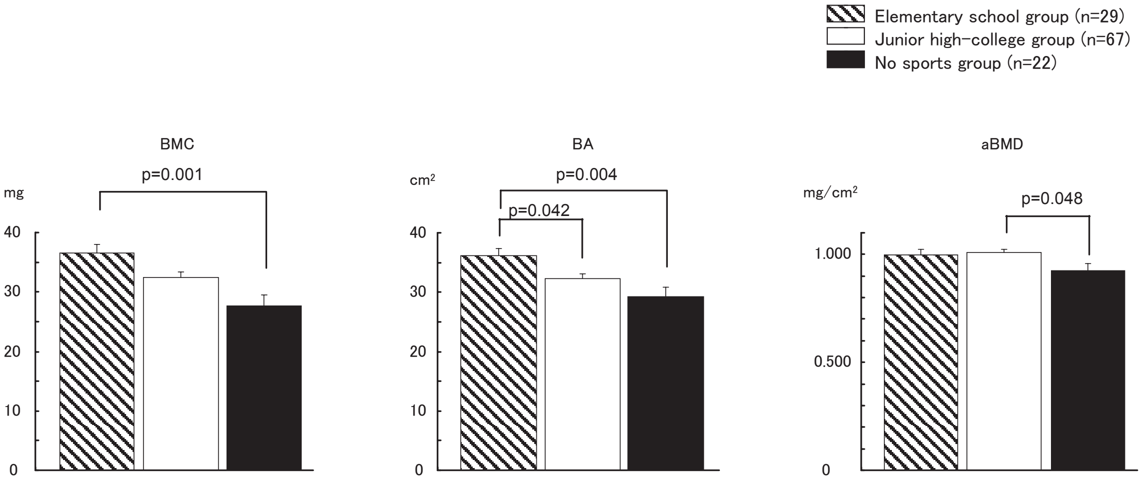

Figure 2 DXA-measured BMC, bone area and aBMD at total proximal femur (n=118).
Values are means±SEM and adjusted for covariate values of height=158.3cm and weight=49.1kg
BMC (Bone Mineral Content)
BA (Bone Area)
aBMD (areal Bone Mineral Density).

3. Results

The physical characteristics of the three groups, classified by the starting age of sports activity based on the results of questionnaire; namely elementary school group (n=29), junior high-college (n=67); junior high school (n=58), high school (n=6) and college (n=3) and no sports group (n=22) (including non-weight-bearing sports (swimming: n=4), no sports participation (n=18)) are presented in Table 1.

No significant differences in age, height, weight, body-mass index (BMI), daily physical activity shown as steps/day, daily dietary calcium intakes or number of oligomenorrhea were seen among the three groups. Both elementary and junior high–college groups showed significantly greater maximal vertical jump height than no sports group. Duration of past weight-bearing sports participation in elementary school group (6.2±2.8 years) was significantly longer than junior high school-college group (4.6±2.8 years). Osteogenic index (OI) in elementary school group was also significantly greater than junior high school-college group.

The partial correlation are significantly correlated between OI and total proximal femur BMC (r=0.240, p=0.009), and aBMD (r=0.278, p=0.002). However, duration of past weight-bearing sports participation had even stronger partial correlation coefficients in total proximal femur BMC and bone area (r=0.431, $p<0.001$ and r=0.383, $p<0.001$) than OI. And also, maximal vertical jump height is significantly correlated with total proximal femur BMC (r=0.428, p=0.001), bone area (r=0.313, p=0.001), and aBMD (r=0.312, p=0.001) (Table. 2).

DXA-measured bone area, BMC and aBMD of the lumbar spine (L2-L4) showed no significant difference among the three groups (Figure 1), and DXA-measured total proximal femur bone strength parameters were shown in Figure 2. Elementary school group showed significantly greater DXA-measured total proximal femur BMC (p=0.001) and bone area (p=0.004) than no sports group. And also, elementary school group showed significantly greater bone area than junior high-college group (p=0.042). Although, there was no significant difference found between elementary school group and no sports group in aBMD at lumbar spine and total proximal femur, junior high-college group showed significantly greater BMD at total proximal femur (p=0.048) than no sports group.

4. Discussion

OI and duration of past weight-bearing sports participation significantly correlated with total proximal femur bone strength parameters. In other word, longer duration of past weight-bearing sports participation and higher impact sports activities are more effective for strengthening proximal femur. Duration of weight-bearing sports participation showed higher correlation coefficients with bone strength parameters than with OI. This result may lead the idea that the starting age of sports participation, especially the pre-puberty elementary school period exercise sensibly affects the exercise inducing BMC and bone geometry.

In torsion and bending, bone strength is proportional to the moment of inertia. If the periosteal perimeter of femoral bone increased second moment of area would increase, since second moment of area is the sum of the square of the distance to the medial axis. While bone strength is closely related to bone structural parameters of the midshaft minimum second moment of area, DXA-measured parameters show a much weaker correlation with bone strength after axial compression loading in the rat foreleg (Warden et al. 2007). Warden et al. (2007) summarized that bone structure offers a better predictor of bone strength changes in response to exercise and subsequent detraining.

We found that although DXA-measured projected two dimensional aBMD in elementary school group did not show any significant differences between junior high-college groups and even with no sports groups, the elementary school group showed significantly greater BMC than the no sports group. On the other hand, junior high-college group showed significantly greater aBMD at total proximal femur than no sports group (p=0.048). DXA measured 2-dimensional total proximal femur bone area in the elementary school group was significantly greater than the both junior height–collage and no sports groups. These findings may suggest that weight-bearing sports activities before and during early puberty exert greater effects on bone geometry and structure, rather than DXA-measured aBMD. Estrogen inhibits the anabolic exercise response at the periosteal surface (Seeman et al. 2002), so maturation status may affect mechanical stress-induced changes in bone geometry. In the elementary school group, mean staring age of sports is 9.2±1.5 years old and the average age of menarche is 12.7±1.5 years old. This result may support the idea that cortical bone expands more effectively toward the outside from the neutral axis of the long bone due to regular weight-bearing exercise before and in early puberty period (elementary school, 6–12 years old) than after puberty (junior high-college, ≥13 years old), and these benefits were effectively preserved in young adult women.

Bass et al. (2002) reported the effects of mechanical loading on size and shape of the humerus using DXA and MRI in young competitive female tennis players, and indicated that increasing bone strength was achieved by modifying bone shape and mass, but not necessarily bone density. Loading before puberty increases bone size and polar second moment of area. After puberty, however, loading increases the acquisition of bone on the endocortical surface with little benefit to polar second moment of area. Our results showed the same tendency and may support the idea that exercise before puberty effectively contributes to bone strength in terms of bone geometry and stricture. McDonald et al. (2007) showed that a high-impact jump training program at around 10 years old in boys significantly enhanced bone strength at the distal tibia after 1.25 school years, as calculated by geometric parameters and cortical bone density. They concluded that bones could adjust strength without increasing or decreasing BMC or BMD by modifying bone size and shape.

Kato et al. (2009) reported that post-menopausal middle-aged women with participation in weight-bearing sports during junior high to high school (12–18 years old) displayed significantly greater BMC in both lumbar spine and femoral neck regions, and also showed significantly greater femoral mid-diaphyseal bone cross-sectional areas, periosteal perimeter and maximum and minimum second moment of area than the non-weight-bearing sports group. Adolescent weight-bearing exercise exerts preservational effects on femoral mid-diaphyseal size and shape. Weight-bearing exercise in youth affects bone, and these effects may be preserved as geometric and structural advantages even after 40 years.

Bone strength, and the consequent risk of fracture, however, is dependent on not only how much bone is present (quantity), but also the distribution (structure) and composition (quality) of bone (Warden et al. 2007). DXA obviously has a limitation in the adequate measurement of bone structure. This is also limitation of our study. Unlike the computed tomography (CT) measurement, the DXA-measured area is planar rather than cross-sectional, but even planar bone geometry may provide the useful information on bone strength.

We identified a significant size difference in the planar bone area and BMC among the groups classified according to sports participation age. The small changes of BMD or BMC brought about by mechanical loading lead to very large increases in the ultimate force (64-87%) and energy failure (64-165%) in rats (Robling et al. 2002). Bone strength can be enhanced substantially through small changes in BMD or BMC if bone is added to mechanically appropriate sites, and young athletes showed significantly greater bone geometric parameters than age-matched controls (Liu et al. 2003; Nikander et al. 2006).

Kohrt et al. (1997) observed a positive high-impact loading effect on femoral neck BMD in postmenopausal women. The training program involved exercises in which forces acting on the skeleton were generated by GRFs, such as walking and jogging, while another program included activities that introduced stress to the skeleton through joint-reaction forces, such as weight lifting and rowing. However, a significant increase in BMD of the femoral neck was only observed in response to the GRF exercise program.

Partial correlation revealed that the maximal jump height, and OI were significantly correlated with the total proximal femur BMC (r=0.428, p=0.001 and r=0.240, p=0.009), BMD (r=0.312, p=0.001 and r=0.278, p=0.002) and bone area (r=0.313, p=0.001, n.s. with OI). And also, the maximum vertical jump height is significantly correlated with OI (r=0.394, p=0.001). This result may explain that the importance of vertical jump height, indicator of leg extension power, in high-impact sports such as volleyball and basketball. Several human studies reported the positive training effects of passive (Fuchs et al. 2001) and active (Bassey et al. 1994; Kato et al. 2006; McKay et al. 2005) jumping on specific sites of bone, especially in the femoral region. Heinonen et al. (2001) identified a significant correlation between the lower extremity muscle cross-sectional area and corresponding cortical bone cross-sectional area measured by magnetic resonance images (MRI) in pre-pubertal girls.

Current daily physical activity shown as steps/day was not correlated positively with DXA-measured values. The load around the hip joint during walking may not be high enough to stimulate the site specific bone modeling in young pre-menopausal women. Interventions in animal studies suggested that a relatively brief exposure to strain is sufficient to stimulate bone formation (Honda et al. 2001; Honda et al. 2003; Lanyon and Rubin 1984; Umemura et al. 1997; Umemura et al. 2002). As few as 5 jumps/day (Umemura et al. 2002), caused by active stimuli, improved the strength of regional bones in immature rats, even though the training required only a short time. Bareither et al. (2005) suggested that the BMD of the proximal femur is not related to peak hip joint moments during locomotion accounting for the influence of body mass in young healthy women. It should be noted that the levels of strain leading to the osteogenic response likely exceeded those generated during typical human physical activities.

Current calcium intake was not positively correlated with total proximal femur after height and body weight was adjusted. Our results showed that calcium intake of 446.1 mg/day was quite low compared with the tentative dietary goal for preventing life-style related diseases of 600 mg/day (Ministry of Health, Labour, and Welfare, Japan. 2005). The National Health and Nutrition Survey in Japan, 2007, showed that the average calcium intake in a similar age group was 445 mg/day so our young pre-menopausal women ingested calcium at comparable levels. However, a greater calcium intake should be recommended to our young pre-menopausal women.

In conclusion, longer duration of past weight-bearing sports participation are effective for strengthening proximal femur. DXA-measured bone strength parameters would provide useful details and revealed that weight-bearing exercise before and in early puberty exerts enlargement effects on total proximal femur size in young adult women. These results may support the concept that weight-bearing exercise in youth affects bone, and that the period before and in early puberty is particularly sensitive for adapting structure, shape and size in response to high-impact activities, and results in effective enlargement of the periosteal surfaces on cortical bone with potential long-lasting benefits for bone health in later life.

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Main Works:

- Kato, T., Yamashita, T., Mizutani, S., et al. (2009). Adolescent exercise associated with long-term superior measures of bone geometry: A cross-sectional DXA and MRI study. British Journal of Sports Medicine, 43: 932-935.
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Membership in Learned Societies:

- Japanese Society of Physical Fitness and Sports Medicine
- Japan Society of Physical Education, Health and Sports Sciences
- Japan Society of Exercise and Sports Physiology
- The Japanese Association of School Health
- Japanese Society of Biomechanics
- The Japanese Society of Nutrition and Dietetics
- Japanese Association of Exercise Epidemiology
- American College of Sports Medicine (ACSM)