J Orthopaed Traumatol (2005) 6:30–35
DOI 10.1007/s10195-005-0077-6

ORIGINAL

High-intensity exercise in female athletes: effects on bone mass and body composition

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Received: 15 May 2004
Accepted: 15 October 2004

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Abstract We investigated bone mass and body composition in young healthy athletic women in order to determine the influence of high-impact physical activity on bone, fat and lean mass. In a case-control study, we studied 68 healthy women, aged 18–45 years, divided in two groups (age and body mass index matched): 39 sedentary women and 29 professional karate athletes. Family and medical histories and information on habits and dietary patterns were collected through a self-administered questionnaire. Bone mineral density (BMD, g/cm^2) of whole body, lumbar spine and proximal femur was measured by means of dual energy X-ray absorptiometry (Hologic QDR 4500A scanner; Hologic, Waltham, USA; version 8.26). Total and subregional fat and lean whole body masses were also measured (grams). Significantly higher femoral and total body bone masses were found in active women compared to sedentary women (total femur: 1.00±0.09 vs. 0.95±0.10 g/cm^2, $p<0.05$; femoral neck: 0.94±0.11 vs. 0.87±0.11, $p<0.05$; trochanter: 0.77±0.10 vs. 0.70±0.08, $p=0.002$; intertrochanter: 1.17±0.09 vs. 1.11±0.12, $p<0.05$; total body: 1.19±0.06 vs. 1.14±0.08, $p<0.05$). Active women also had lower fat mass (total: 16510±4430 vs. 20736±7883 g, $p=0.007$; limbs: 9952±2779 vs. 11888±4147, $p=0.027$; trunk: 5807±1970 vs. 8325±4113 $p=0.001$) and higher limb lean mass (15574±2124 vs. 14532±2034 g, $p=0.05$). A significantly lower calcium intake was registered in active women. Oral contraceptive use appeared to significantly increase femoral bone density. Physical activity increased bone mass in young active women, and this effect seemed to be superior to that of dietary calcium intake.

Key words BMD • Densitometry • Fat mass • Karate • Lean mass • Physical activity

Introduction

Osteoporosis is a reduction of bone mass that leads to an increase in fracture incidence. It affects mainly postmenopausal women and elderly and represents a world-wide health problem. The peak of bone mass achieved before the third decade of life and factors that influence bone loss determine the amount of bone mass present at a given time in adult age (National Institutes of Health Consensus Development Conference Statement. Osteoporosis Prevention, Diagnosis, and Therapy. Bethesda, USA 2000, March 27–29; http://consensus.nih.gov). Genetic characteristics, hormonal status, and lifestyle conditions, such as dietary calcium intake and physical activity, are known to be the most important factors acting on bone.

Physical activity can reduce fracture risk by increasing bone mass during youth, by preventing bone loss and by improving muscular and articular fitness that decreases the risk of falling [1].

While there is general agreement in literature about effectiveness of physical activity on development of peak bone mass and on its maintenance during life, there are still uncertainties about the type, intensity, duration, and frequency of exercise [2]. A high-impact exercise program has been reported to be more effective than a low-impact one in increasing bone mass of weight-bearing skeletal sites [3–5]. Only a few works also deal with its effect on body composition [6, 7], but data are referred to a male athlete population or to pre-menarchal girls.

No single study is available about the effect of high-impact exercise on bone mass and body composition in pre-menopausal athletes. The aim of this study was to assess bone, fat and lean mass in pre-menopausal young athletes and in a sedentary control group.

Patients and methods

Healthy pre-menopausal women, aged 18–45 years, were recruited and divided into two groups: (i) sedentary women (n=39), selected among the employers of the main teaching hospital in Milan through a formal request for volunteers mailed to all the hospital departments, and (ii) physically active women (n=29), recruited through advertising in several karate clubs of the same city. The active women were competing athletes at international level and they reported strenuous exercise for about 18 hours weekly: two hours of aerobic and one hour of anaerobic exercise daily for six days. Sedentary women reported simple walking exercise for a maximum of about four hours weekly. The mean age at the start of competing activity among the athletes was 17 years (range, 15–18 years), while the sedentary women never did any competitive physical activity during their adolescence and young age. Women presenting the following characteristics were not included in the study: natural or surgical menopause; pathologies and surgery that may influence the hormonal pattern such as ovariectomy; long-term drug therapy for chronic pathologies; hormonal replacement therapy; anorexia; alcohol and drug abuse.

Every woman was asked to sign an informed consent form and to fill out a self-administered questionnaire concerning her family history, habits and medical history. Dietary information was collected through a food frequency questionnaire which included pictures of the portions of the main foods. It was a modified version of the questionnaire used by Willett et al. [8], validated for suitability to the Italian population and for acceptability in a pilot study on 10 healthy women. Calcium intake was calculated by adding up the mean calcium content of each component of the diet assumed by each participant in the week previous to the interview. Mean caloric intake in the same period was also calculated in both groups.

Bone mineral density (BMD) at the lumbar spine, proximal femur of the dominant leg and whole body was measured in all the subjects by means of dual energy X-ray absorptiometry (DEXA) densitometer (Hologic QDR 4500A scanner; Hologic, Waltham, USA; software version 8.26). The BMD values were expressed as bone mineral content (grams) divided by the area of interest (square centimeters). For lumbar spine, the value of BMD of the entire region of interest was considered (measured from L2 to L4). For proximal femur, the values of BMD of the whole femur and of the following subregions were considered: neck, trochanter, intertrochanter, Ward's triangle. We also considered the values of total BMD and leg BMD of the whole body scan.

Regarding body composition, we measured: total fat and total lean body mass; trunk fat and lean mass; limb fat and lean mass. These values were expressed in grams.

The in vivo coefficient of variation (CV) of scan-rescan DEXA measurements at our center was: for lumbar spine, 0.5%; for proximal femur, 0.7%; for whole body scan (total), 0.7%; for whole body scan (legs), 1.3%. CV for whole lean mass was 1.1% and for whole fat mass 1.9%. The individual exposure dose was less than 7 mRem.

Comparisons between means were performed by *t* test for unequal variances to allow for the small sample size; comparisons between proportions were performed by chi-square test.

Multivariate analysis was conducted using the SAS package version 6.12. The general linear model (GLM) was performed, using the variables of bone mineral density as dependent variables. Independent variables included age (years), BMI [weight in kg/(height in m)^2], physical activity (hours per week), smoking (yes/no), dietary calcium intake (mg/day), oral contraceptive use (yes/no), and family history for osteoporosis (yes/no). The model was also run by substituting BMI with weight and height.

Results

Bone mass and body composition were investigated in 39 healthy sedentary women and in 29 healthy physically active women (Table 1). The only statistically significant difference between the two groups was the higher calcium dietary intake reported by the sedentary women (50%), besides the obvious difference in hours per week of physical activity (392%).

Values of bone mineral density of whole body and its subregions are presented in Table 2. The mean values for all the variables were higher in active women than in sedentary women, and there was a significantly higher density in total body (4.3%), total femur (5.2%), femoral neck (8.0%), intertrochanter (5.4%) and trochanter (10%).

Fat mass was significantly higher in sedentary women (total, 25.5%; trunk, 43.3%; limbs, 19.4%), while there was no significant difference in lean mass between the two groups (Table 3).

Multivariate analysis (Table 4) showed that there was an independent association of physical activity with the mineral composition of femur, femoral neck, trochanter,

Table 1 Characteristics of the study population, by physical activity level. Values are mean (SD) unless otherwise indicated

	Sedentary women (n=39)	Active women (n=29)
Age, years	31.3 (6.4)	30.6 (6.0)
Education, n (%)		
Junior high school	8 (20.5)	5 (17.2)
High school	25 (64.1)	14 (48.3)
University	6 (15.4)	10 (34.5)
Body mass index, kg/m^2	22.9 (4.2)	21.8 (3.4)
Weight, kg	59.1 (11.8)	55.0 (6.5)
Height, cm	159.5 (5.6)	162.6 (6.5)
Daily Ca^{++} dietary intake, mg	1332.1 (721.1)*	886.5 (582.4)
Daily caloric intake	1918 (931)	1963 (722)
Current smokers, n (%)	15 (38.5)	5 (17.2)
Family history of osteoporosis, n (%)	19 (48.7)	12 (41.4)[a]
Oral contraceptive use, n (%)	16 (41.0)	9 (31.0)
Physical activity, h/week	4.0 (2.2)*	19.7 (1.5)

[a] 4 subjects did not answer the question
*p=0.006 vs. physically active women

Table 2 Bone mineral density (g/cm^2), by study group. Mean (SD)

	Sedentary women (n=39)	Active women (n=29)
Lumbar spine	1.05 (0.11)	1.09 (0.10)
Femoral neck	0.87 (0.11)	0.94 (0.11)*
Trochanter	0.70 (0.08)	0.77 (0.10)**
Intertrochanter	1.11 (0.12)	1.17 (0.09)*
Total femur	0.95 (0.10)	1.00 (0.09)*
Ward's triangle	0.79 (0.16)	0.85 (0.14)
Total body	1.14 (0.08)	1.19 (0.06)*
Legs	2.37 (0.16)	2.43 (0.26)

*p<0.05; **p=0.002

Table 3 Fat and lean mass (g), by study group. Values are mean (SD) unless otherwise indicated

	Sedentary women (n = 39)	Active women (n = 29)	*p*
Fat mass			
Trunk	8325 (4113)	5807 (1970)	0.001
Limbs	11888 (4147)	9952 (2779)	0.027
Total	20736 (7883)	16510 (4430)	0.007
Percent of weight	35	30	0.050
Lean mass			
Trunk	18037 (1714)	18802 (2100)	0.120
Limbs	14532 (2034)	15574 (2124)	0.050
Total	35437 (3724)	36898 (3991)	0.136
Percent of weight	60	67	0.050

Table 4 Multivariate analysis on factors contributing to bone mass

Independent variables	Total femur F	Total femur *p*	Femoral neck F	Femoral neck *p*	Trochanter F	Trochanter *p*	Intertrochanter F	Intertrochanter *p*	Lumbar spine F	Lumbar spine *p*
Physical activity	5.52	0.02	9.99	0.003	5.04	0.03	4.45	0.04	0.08	0.77
Smoking	1.15	0.29	0.59	0.44	0.12	0.73	0.91	0.34	0.00	0.97
Dietary calcium intake	0.20	0.90	0.25	0.86	0.17	0.92	0.18	0.91	1.00	0.40
Oral contraceptive use	4.28	0.04	2.56	0.11	1.75	0.19	4.39	0.04	0.53	0.47
BMI	1.15	0.29	0.62	0.45	0.15	0.75	1.02	0.41	1.02	0.41

BMI, body mass index

and intertrochanter. Oral contraceptive use was positively associated with femur and intertrochanter mineral density. The model included other variables (age, BMI, family history for osteoporosis) which were not significantly associated. The substitution of weight and height to BMI did not change the results. None of the independent variables considered showed any association with the other parameters of bone mineral density, or with lean or fat body mass (data not shown).

Discussion

The determinants of peak bone mass and the age at which this is attained are unclear; however, they are purported to include genetic, individual and environmental factors. Both men and women lose bone at a rate of 0.3%–0.5% per year from the fourth decade [9], but the process starts after peak bone mass is reached, and this is acquired around the age of 16–18 years in USA [10], likely later in Europe [11]. Heritable factors probably influence peak bone mass by altering skeletal growth [12]. Physical activity is a well known factor acting positively on bone mass. Exercise stimulates bone formation and decreases bone resorption by inducing strain, which generates fluid streams in the bone canaliculi connecting osteocytes, cells that acts as mechanosensors [13]. During growth, exercise produces hypertrophy of bones, in addition to that of muscles, and contributes to higher peak bone mass [1, 14]. However, some Finnish authors did not find any relationship between the increment rate of bone density and physical activity in children and adolescents [15].

Among different types of physical activity, weight-bearing exercise, dynamic intermittent loading and high resistance training are the most effective in stimulating bone formation and in maintaining bone mass, whereas physical inactivity has been implicated in bone loss [14]. Low intensity exercise has no or low effect on bone mass, as demonstrated by a Finnish study [4], observing that long-term regular aerobic physical activity in middle-aged men had no effect on the age-related femoral bone loss. The highest bone mineral density is reached in weight-lifters and squash players [16]. Weight-bearing activity can increase BMD in children, as demonstrated by a controlled prospective study [7], but a complete agreement fails about the effect of exercise on bone mass in adults. A recent meta-analysis indicated a significant effect of exercise programs on BMD in adults and on rates of bone loss in the elderly, with prevention or reversal of about 1% of bone loss per year both in lumbar spine and femoral neck [17]. The results were observed also in post-menopausal women [5], where a high-intensity strength exercise for 45 minutes twice a week significantly increased lumbar and femoral BMD. However, other studies have demonstrated that physical activity in older athletes has no effect on BMD, although it improves muscular performance and balance [18]. A study has shown that athletes lose bone and muscle at the same rate as their older peers [19]. Moreover, some authors [20] assumed that athletes already have substantially higher BMD levels than controls at the beginning of their training, probably due to a selection bias, because subjects having larger muscles and bones preferentially become athletes. Regarding the selection bias in population recruitment as explanation for the between-groups difference, it is noticeable that in our study the women were matched by age and body mass index and had an identical total lean mass. Therefore, it is unlikely that any selection bias had occurred in terms of their body characteristics.

In our population, active women performing high-intensity physical activity had a higher bone mass than sedentary women, suggesting that dynamic high-impact training is an independent factor positively associated with bone mass. Greater bone mass was detected in total body, in total femur and in its subregions, excluding Ward's triangle. Thus, only skeletal sites prevalently constituted by cortical bone had an increased bone mass;

in fact Ward's triangle, which is a trabecular femoral bone region, did not show a similar pattern. The bone density of lumbar spine, mainly constituted by trabecular bone, was also not significantly different between the groups.

Our data seem to confirm the results of other authors [2, 3, 6, 13, 21–23], who claimed that the increase in BMD is site specific and related to high strains created during sports-training at certain skeletal sites by muscle stress and gravitational forces. In fact, sports without relevant gravitational forces, even if with high-intensity effort, like swimming and water-polo, do not lead to an increase in bone mass [6, 22].

Weight-bearing training is a powerful osteogenic stimulus, while non-weight-bearing exercise, even if long-term, has no positive skeletal effects [4, 13, 22]. The increased BMD of weight-loaded skeletal regions lasts for many years even after high-intensity physical activity has ceased [13, 24]. Low-intensity training also has a protective effect on bone in the elderly, since weight-loaded sites present a lower bone loss than unloaded sites [25].

Our two groups, athletic and sedentary women, had similar values of BMI, weight and height, and therefore variations in fat and lean mass were actually reflected by body composition. The athletic women presented lower fat mass values at all the measured sites (total, limbs and trunk) with a significant reduction in fat percentage of body weight. These data confirm some observations by Andreoli et al. [6] and Taffee et al. [22], particularly those regarding highly trained athletes submitted to gravitational forces.

The difference in limb lean mass observed between our two groups was statistically significant, like the difference in the lean mass percentage of body weight, whereas total and trunk lean masses did not show any between-groups difference. This regional lean mass distribution reflects the training characteristics of our athletes, prevalently involving legs. We did not find similar data in the literature, since Andreoli et al. [6] found a higher value also in total lean mass of athletes, while Morris et al. [7] and Taffee et al. [22] showed a gain in total lean mass in active population, without paying attention to lean mass distribution. However, Andreoli et al. [6] demonstrated in the same male population that high-intensity activities involving arms and legs lead to an increase in appendicular muscle mass, even if they did not find a significant difference between controls and karate athletes.

Calcium is important for the growing skeleton, while its demand declines rapidly after adolescence. However, calcium supplementation during growth causes only 1% acceleration in increasing BMD, without altering peak values. In adults calcium intake only accounts for about 3% of the variance in BMD. Moreover, calcium supplementation was not effective in reversing osteoporosis [26]. In our population, despite a higher dietary calcium intake, the sedentary women had a lower bone mass than the active women, confirming that calcium intake is a less important factor in determining bone mass than exercise, as reported by Friedlander et al. [27]. A longitudinal cohort study similarly concluded that weight-bearing activity during youth is more effective on bone mass than calcium intake [28]. Other authors found different nutritional behaviors in active and sedentary populations. Andreoli et al. [6] reported a lower dietary calcium intake in controls than in athletes, but control subjects also had a lower daily caloric intake, whereas our study groups had similar nutritional patterns. Nelson et al. [5] found a similar calcium dietary intake in sedentary and active subjects. Despite the differences in calcium intake of their populations, all these authors agreed regarding the positive effects of exercise on bone mass.

Our multivariate analysis showed that, like exercise, oral contraceptive use is also a factor that positively influences bone density of the femur. However, there was no significant difference in oral contraceptive assumption between our sedentary and athletic women. Therefore, estrogens unlikely were a confounding factor in our study.

In conclusion, our data confirm that high-impact physical activity during early adulthood is efficacious in increasing bone mass of loaded skeletal sites and could be superior than other treatment options, such as prescription of calcium supplementation, in order to prevent bone loss and osteoporotic fractures in the elderly.

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