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EFFECTS OF PHYSICAL ACTIVITY AND FOOD INTAKE ON BONE MINERALISATION IN FEMALE EX-ATHLETES

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Abstract

The aim of the study was to assess the effects of physical activity and food intake on bone mineralisation, density and stiffness in female ex-athletes, as compared with women who never practised sports. The following questions were formulated: 1. Whether the presumably beneficial effect of high physical activity on bone mass (in the period of its peak level) can be sustained after the sport career has been terminated, and 2. Whether the present lifestyle of ex-athletes, i.e. their physical activity and food intake, may influence their bone density and strength.

Methods: A group of 43 female ex-athletes aged 16–34 years, who terminated their sport careers 1–5 years earlier, and 48 women in similar age, who never practised sports, participated in the study, the criteria of eligibility being were a good health status and normal ovarian function. The following measurements were carried out: body height and mass, relative fat content, bone mineralisation in the lumbar spine (L_2 - L_4) by densitometry, bone stiffness in the calcaneal bone by ultrasonography. All subjects were interviewed as to their past sport career, present physical activity and ovarian function in the past. The food intake was assessed using three 24-h recalls.

Conclusions: The following conclusions were drawn: 1. Bone density of the lumbar spine (L_2 – L_4) of ex-athletes was significantly higher than that of women never practising sports. 2. A higher bone mass of ex-athletes compared with untrained women was probably due to a more active lifestyle of the former, apart from their past sport engagement. 3. The present calcium intake by ex-athletes, most of whom followed the recommended values, seems to have contributed to bone mineralization. 4. The beneficial effect of a high physical activity on bone quality throughout the sport career in the past is likely to be maintained when the lifestyle is health-directed.

Key words: physical activity, food intake, bone mineralisation, women, female ex-athletes

Introduction

Osteoporosis is among the principal health risks worldwide. Epidemiological data indicate that the risk of osteoporosis is associated with everyday physical activity steadily diminishing, i.e. with a reduced mechanical load applied to bones and with irregular nutrition, especially with insufficient calcium intake (1-5). All those factors, together with the genetic and hormonal ones, play paramount role in attaining the peak bone mass in the periods of growth, bone mass stabilisation, in the advanced age (3,6-9). The incidence of osteoporosis in the population aged over 35 years is expected to amount to 2.26 million in 2050 compared to 1.6 million in 1990 (5). Based on that prognosis, some preventive measures have been undertaken which include two strategies: population-oriented and individual, pertaining to high-risk individuals. Changes in dietary habits and an augmented physical activity are of utmost importance in both strategies.

The aim of the study was to determine the bone mineral density and strength of female ex-athletes, subjected to intense physical activities in the past, compared with the untrained ones. In particular, answers to the following questions were sought: whether the presumed beneficial effect of high physical activity on the bone mass at the period of its peak status can be sustained after the sport career had been terminated, and whether the present physical activity and food intake of female ex-athletes have an effect on bone density and strength.

Material and methods

Subjects: A group of competitive ex-athletes women aged 16–34 years, mostly members of National teams, who terminated their sport career 1–5 years earlier, participated in the study. They represented swimming (n = 11), rowing (n = 6), gymnastics (n = 7), figure skating (n = 6), speed skating (n = 6) and team games (n = 7). Another group of women (n = 48) in the same age range, who never practised sports, were initially divided into age categories corresponding to those of ex-athletes. Since no differences between age subgroups were found for any variable studied, all untrained women were combined into one control group.

All subjects submitted their written consent to participate in the study, which was accepted by the local Committee of Ethics. The criteria of inclusion were good health status and regular ovarian function as confirmed by daily measurements of basal body temperature in the morning for half a year. Basic anthropometric data of subjects are presented in Table 1 (10).

***Questionnaire data*:** All ex-athletes were interviewed as to their past sport career and ovarian function, present physical activity and dietary habits. The questionnaire contained questions about the age of starting regular training, training experience, weekly loads, and the age of having terminated sport career. The present leisure activity was rated according to the number of hours per week devoted to recreational activities: 0 – no activity; 1 – low activity (1–2 h); 2 – moderate activity (3–4 h); 3 – high activity (5–6 h); 4 - very high activity (over 6 h). For the purpose of data analysis, ratings 0 and 1 were combined, and the same applied to ratings 3 and 4.

The questions pertaining to the past ovarian function included the age at menarche, regular or irregular cycles, secondary amenorrhea, and contraception.

Energy and selected nutrients intakes were assessed from nutrition history and from 24-h recalls (two workdays and one weekend day). Daily intakes of energy, protein, calcium, magnesium and phosphorus were determined with the use of DIETUS software based on Polish nutrition tables (11). Results were confronted with RDA for Polish population (safety level of intake) taking into account age, body mass and physical activity of studied women (ex-athletes – high, control group – low). It was assumed that mean intake of given component ± 10% was well within normal limits (12). Intakes of individual nutrients lower than 2/3 of the RDA were considered as a hazard of deficiency of that nutrient (13).

Densitometric and ultrasound measurements: Bone mineral content (BMC; g) and density (BMD; g/cm^2) were determined for the lumbar spine ($L_2 – L_4$) by Dual Energy X-ray Absorptiometry with the use of Lunar DPX-L device (USA). The precision of measurements was 0.5–2.5% and reproducibility 2 – 4%. The results were expressed in SD-units related to the peak bone mass (T-score) or to age (Z-score). Bone elasticity and strength (bone stiffness index) were determined in the calcaneal bone by quantitative ultrasound (QUS) with the use of Lunar Achilles device (USA), the precision of measurements amounting to 1.4–1.5%. The measurements were expressed as relative to peak bone quality of women aged 20–29 years or to women of corresponding age (14).

***Data processing*:** The distributions of all study variables showed no significant deviations from normality by graphical analysis. The data were subjected to one- and two-way ANOVA followed by Tukey's test. Frequency data were analysed with the use of chi-square function in the logarithmic form (15).

Results

Information on sport career and present physical activity of subjects studied is presented in Table 2. Untrained women (about 2/3) and ex-swimmers (over one-half) proved the least activity at present. About 1/3 of ex-athletes declared high or very high activity, especially the ex-rowers (over 80%).

Mean age at menarche of ex-athletes was 13.57 ± 0.32, and that of the untrained women – 13.72 ± 0.98 years. Thirty-four ex-athletes reported having

Table 1. *Anthropometric data of the subjects (means ± SD)*

	1	2	3	4	5	6	7
	Swimming	Rowing	Gymnastics	Figure skating	Speed skating	Team games	Control
n	11	6	7	6	6	7	48
Age (years)	21.7±2.9 *6	28.0±4.8 *4	21.4±2.6 *6	17.8±1.2 2.6	24.0±2.6	29.7±4.3 *1,3,4	23.9±5.4
Body mass (kg)	64.4±10.3	70.0±8.1 *3,4	57.0±4.8 *2	54.1±4.3 *2	62.3±7.8	65.2±6.7	60.6±8.3
Body height (cm)	170±6	176±6 *3,4	163±7 *2	164±4 *2	172±7	170±5	169±5
BMI (kg·m^{-2})	22.2±2.7	22.7±1.2	21.5±1.4	20.1±0.8	21.2±2.5	20.9±1.5	21.8±3.6
Body fat content (%) [7]	23.4±5.0	20.6±4.1	24.5±3.2	20.2±3.0	23.6±3.3	19.8±2.8	24.4±3.7

* The numbers pertain to sports for which significant (p<0.05) differences were found

Table 2. *Sport career and present physical activity of women studied (means ± SD)*

No.	Group	(n)	Training history			Post-sport career period (years)	Present physical activity(h/week)					
			Age at starting training (years)	Training experience (years)	Weekly training load (h)		None or low (0-2)		Moderate (3-4)		High and very high (5 and more)	
							n	%	n	%	n	%
1	Swimming	11	8.90±0.83	7.86±2.23	23.9±3.7 *6	4.95±1.73 *4	6	54	5	46	-	-
2	Rowing	6	13.00±1.62	11.50±3.27	25.8±8.1 *4,6	4.23±2.53	-	-	1	17	5	83
3	Gymnastics	7	6.42±0.97	9.71±0.75	19.0±4.3	4.57±1.98	1	14	2	29	4	57
4	Figure skating	6	6.66±0.50	9.50±1.87	16.1±3.7 *2	1.66±0.81 *1	4	67	2	33	-	-
5	Speed skating	6	11.16±0.98	10.50±2.88	18.3±4.2	3.25±1.03	3	50	2	33	1	17
6	Team games	7	11.57±2.07	12.00±3.91	15.0±4.3 *1,2	4.71±1.60	-	-	3	43	4	57
7	Control	48	-	-	-	-	33	69	15	31	-	-

*p<0.05 differences statistically significant between given group and those indicated by numbers

regular menstrual cycles in the past, and only 9 other ones had irregular cycles, the acyclic periods lasting never longer than 3 months. All untrained women menstruated regularly. Using contraception reported 13 ex-athletes and 5 untrained women.

Mean energy intake amounted to 2233 ± 215 kcal in the control group and ranged from 2014 ± 121 to 2264 ± 368 kcal in various groups of ex-athletes (Table 3) and was not in-line with the recommendations (12,13). An average protein and phosphorus intakes were above the RDA in all groups studied. On the contrary, magnesium (with the exception of ex-rowers and women practicing team games) and calcium intakes was below the recommendations. The lowest average calcium intake was noted in the control group – 533±52mg/day. Individual calcium intake was insufficient, i.e. below 2/3 of RDA, in as many as 51% of ex-athletes and 79% of control women.

Table 3. *Daily intake (mean ± SD) of energy, protein, calcium, magnesium and phosphorus recorded in women studies*

No.	Group	(n)	Energy (kcal)	Protein (g)	Magnesium (mg)	Calcium (mg)	Phosphorus (mg)	Ca : P
1	Swimming	11	2082.3±177.9 (71.7) #	56.2±19.3 (108.1)	192.9±68.7 (68.8) *2,6	583.9±109.6 (53.1)	883.2±219.2 (110.4)	1: 1.5
2	Rowing	6	2264.5±367.8 (78)	59.7±18.7 (106.6)	302.5±65.2 (108.0) *1,7	726.1±55.7 (90.7)	1090.5±209.4 (167.6)	1: 1.5
3	Gymnastics	7	2020.0±168.9 (73.4)	58.3±13.0 (121.4)	217.8±50.4 (77.7)	744.2±107.5 (67.6)	1015.8±178.2 (126.9)	1: 1.4
4	Figure skating	6	2013.8±121.0 (77.4)	66.5±12.4 (133)	235.4±52.9 (73.5)	656.5±112.8 (59.7)	1076.2±208.8 (134.5)	1: 1.6
5	Speed skating	6	2157.0±277.5 (74.3)	64.9±19.2 (135.2)	243.4±68.1 (86.9)	668.7±163.0 (60.7)	1059.7±174.2 (132.4)	1: 1.6
6	Team games	7	2146.0±325.2 (76.6)	74.1±23.4 (142.5)	302.0±65.4 (107.8) *1,7	767.1±169.5 (95.8)	1196.0±201.7 (184) *7	1: 1.6
7	Control	48	2233.7±215.1 (117.5)	58.0±14.0 (120.8)	186.9±20.6 (66.7) *2,6	533.3±52.0 (48.4)	849.5±144.5 (106.1) *6	1: 1.6

Absolute and relative (%) intakes of nutrients – relative intakes vs. the "safe intake norms"
* p<0.05 statistically significant differences between given group and those indicated by numbers

Table 4. *Mean values (±SD) of bone quality indices in female ex-athletes and in control group*

No.	Group	(n)	Bone mineral content (g)	Bone mineral density			Bone stiffness index	
				($g \cdot cm^{-2}$)	Relative to peak bone mass (%)	Relative to age (%)	Relative to peak bone quality (%)	Relative to age (%)
1	Swimming	11	54.6±11.4 *2	1.237±0.151	103.2±13.4	103.7±12.1 *6	103.4±8.9	104.4±9.4
2	Rowing	6	68.4±13.2 *1,3,4,7	1.360±0.180	113.3±15.8	112.5±15.8	112.8±18.5	117.3±19.4
3	Gymnastics	7	52.3±6.1 *2,6	1.278±0.090	106.3±8.0	109.3±7.3	104.4±13.0	105.7±14.2
4	Figure skating	6	46.8±6.9 *2,6	1.218±0.162	100.5±7.0	100.0±7.7 *6	96.8±8.7	95.3±8.8*6
5	Speed skating	6	56.3±3.3	1.279±0.010	106.8±1.7	107.8±2.13	100.6±11.3	102.0±11.5
6	Team games	7	65.0±5.9 *3,4	1.414±0.142	117.7±11.5	119.1±13.2 *1,4,7	118.2±21.1	126.1±21.2 *4
7	Control	48	54.5±6.8 *2	1.223±0.102	102.1±9.0	103.6±8.1 *6	104.8±13.3	107.2±14.2
1-6	All athletes	43	57.0±10.9	1.293±0.149 *7	107.6±11.9 *7	108.4±11.9 *7	106.0±14.9	108.3±16.8

* $p<0.05$ statistically significant differences between given group and those indicated by numbers

Bone status indices

Mean BMC value determined for the lumbar spine ($L_2 - L_4$) was significantly highest in ex-rowers and team game players and amounted to 68.4 ± 13.2 and 65.0 ± 5.9 g, respectively. The same was found for BMD (1.360 ± 0.180 and 1.414 ± 0.142 $g \cdot cm^{-2}$, respectively) and bone stiffness index (113 ± 18 and 118 ± 21%, respectively) but not statistically significant (Table 4). Individual BMD values were within normal limits in all cases except one ex-swimmer whose Z-score amounted to –1.61 indicating osteopenia according to WHO criteria.

Bone parameters recorded in all ex-athletes were standardised against the respective means and standard deviations recorded in the control group (15). The sums of standardised values enabled classifying ex-athletes into two subgroups: I – team games and rowing and II – swimming, gymnastics and skating (Fig. 1). Both groups differed significantly with respect to sums of the standardised values.

Bone parameters recorded in all ex-athletes combined tended to be higher and in case of BMD the values were significantly higher compared with the control group ($p<0.05$) (Table 4).

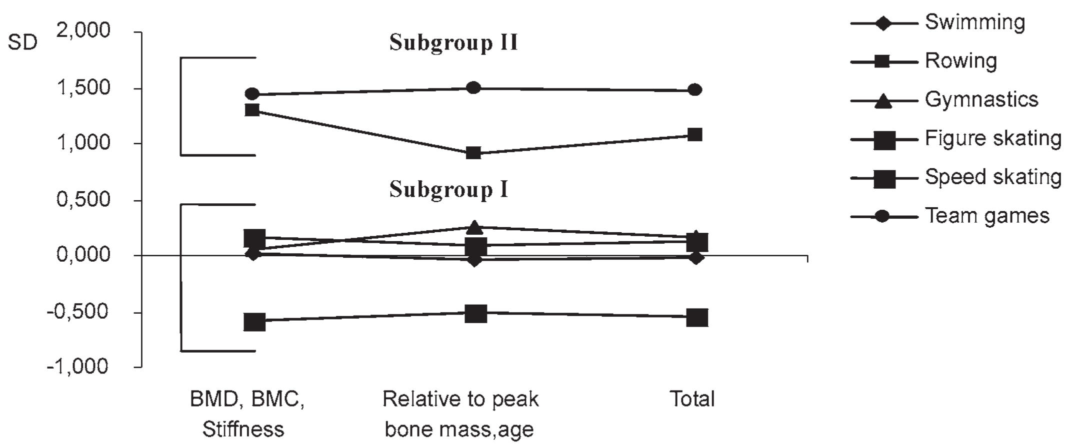

Fig. 1. *Mean values of bone parameters in subgroups standardized against the control group*

Table 5. *Arithmetic mean daily intakes (± SD) of energy, protein, calcium, magnesium and phosphorus recorded for female ex-athletes and for control women*

No.	Group	Age (years)	Body mass (kg)	Energy (kcal)	Protein (g)	Magnesium (mg)	Calcium (mg)	Phosphorus (mg)
1	Ex-athletes, Subgroup I (n=13)	28.9±4.4	64.8±8.7	2201±336 (78.6)#	67.5±10.9 (129.8)	302±31 (107.8) ***2,3	748.1±121.6 (93.5) **3	1147.3±160.2 (176.5) **3
2	Ex-athletes, Subgroup II (n=30)	21.3±3.1	60.3±8.5	2069±188 (75.2) *3	60.5±16.5 (126)	217±31 (77.5) ***1	652.8±83.3 (59.3) *3	988.1±121.1 (123.5) *3
3	Control (n=48)	23.9±5.4	60.6±8.3	2233.7±215.1 (117.5) *2	58.0±14.0 (120.8)	186.9±20.6 (66.7) ***1	533.3±52.0 (48,4) **1*2	849.5±144.5 (106.1) **1*2

Absolute and relative (%) intakes of nutrients – relative intakes vs. the "safe intake norms"
* $p<0.05$; ** $p<0.01$; *** $p<0.001$ – statistically significant differences between given group and those indicated by numbers

Table 6. *Present physical activity of ex-athletes, classified by bone quality, and of control women*

Groups \ Activity		Low or none		Moderate		High and very high		Total		χ^2
		n	%	n	%	n	%	n	%	
Ex-athletes	Subgroup I*	0	0	4	30.7	9	69.2	13	100	44.1
	Subgroup II**	14	46.6	11	36.6	5	16.6	30	100	
	Total	14	32.5	15	34.9	14	32.5	43	100	27.0
Control		33	68.7	15	31.3	0	0	48	100	

* Subgroup exhibiting highest values of bone quality indices
** Subgroup exhibiting lower values of bone quality indices

Bone indices and the energy and select nutrients intakes

Mean intakes of energy and of selected nutrients (protein, Ca, Mg, P) in the two groups of ex-athletes and in the control group are presented in Table 5. The diets of ex-athletes contained more minerals but less energy than those of control subjects.

Present physical activity and bone status of women

About 2/3 of women from the control group undertook no or very little leisure activities, the other ones reported only moderate but no high or very high activity. In contrast, only 1/3 of ex-athletes reported low activity, another 1/3 - moderate and the remaining ones - high or very high activity. Moreover, those ex-athletes, whose bone status was high, declared also significantly highest leisure activities ($p<0.0001$) (Table 6).

Combined effects of the present physical activity and nutrition on bone status

In order to take into account the synergic effect of nutrition and exercise on bone status, all subjects were classified into the following 4 categories:

a. low or none physical activity, calcium intake lower than 67% (521,6 mg/24h) of the RDA
b. low or none physical activity, calcium intake higher than 67% (636,8 mg/24h) of the RDA;
c. moderate-to-very high physical activity, calcium intake lower than 67% (512,5 mg/24h) of the RDA;
d. moderate-to-very high physical activity, calcium intake higher than 67% (806,2 mg/24h) of the RDA.

The two intermediate groups (b and c) were alike with respect to all bone quality indices, while Group d tended to be superior to the lowest group (a) in all those indices (differences not statistically significant) (Fig. 2).

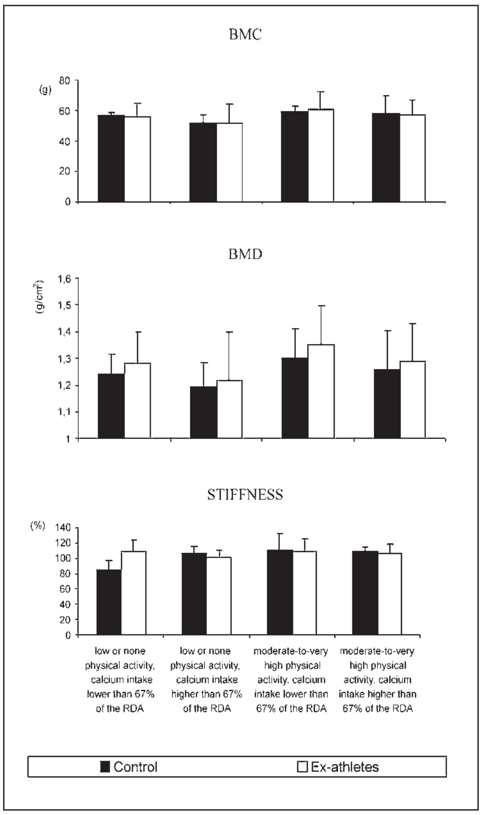

Fig 2. *Combined effect of calcium intake and physical activity on BMC, BMD and Bone stiffness index*

Discussion

The discussion on the effects of physical activity on bone density and quality, initiated in the sixties, has been continued (16,17). Inasmuch many questions remain still unanswered, it is presumed that girls who train in the adolescence period attain a higher peak bone mass than the untrained subjects (18,19). Most authors suggest that practising sports exerts beneficial effects on the bone both during the sport career and after having it terminated (7,20,21,24). Those data are indicative of a possibility to sustain the bone mass achieved in childhood and adolescence, as supported by Orwoll et al. (9), who studied about 8000 women over 55 years of age, in whom they demonstrated a positive correlation between the present bone mass density (BMD) and physical activity in the past.

The findings of this study on ex-athletes who used to be engaged in sports for 8 – 12 years demonstrated that the present BMD was significantly higher ($p<0.05$) than control subjects (Table 4). It has been reported that exercise-derived mechanical stimuli have greatest impact in those areas of bones where the strain is highest, e.g. tennis player's arm (23,24), while bone density in those regions of the skeleton of female gymnasts, which were subjected to lower than average loads, was comparable to that observed in control subjects. Higher values of bone indices found in this study in ex-rowers and ex-team-game players are indicative of beneficial effects on bone quality of such exercise loads, which are characteristic for those sports, i.e. activate large muscle groups (Fig. 1).

Physical activity, both in the young age and in the subsequent periods of life, contributes to bone mineralisation and density at the adult age (9,20,26). Since the beneficial effect of sport training in the past should be supported by continuing physical activities in the adult age, women which discontinued their sport careers should assume such a lifestyle. A sedentary lifestyle may easily destroy the beneficial effect of past physical activity on the bone mass, and even reduce the period of its stabilisation. Ethrington et al. (20) reported that adult women, who regularly spent one hour weekly on any motor activity, had higher BMD than sedentary women. So far, participation of Polish men and women in various forms of leisure activities was reported to be unsatisfactory and decreasing with age (27). In European Union countries, highest percentage of respondents who declared a high physical activity was found for Finland (30.2%), Poland occupying the lowest position (6.4%) (28).

The dietary habits, including calcium uptake throughout the lifespan, is as important for an adequate bone mineralisation and density as physical activity. According to Sandler (29), calcium uptake lower than 500 mg/day may decrease bone mineralisation. As reported by Recker et al. (30), the increment in bone mass of lumbar spine, of forearm and of the entire skeleton of women between 19 and 26 years of age, is positively correlated with the dietary habits. Studies on various female athletes, conducted in the nineties, showed that a reduction of bone mass is often associated with dietary disorders (31,32) and although athletes usually had a higher calcium intake than the general population, that intake was often too low considering the high requirements (33,34). In this study, the present calcium uptake was also lower according to RDA for Polish people and only those ex-athletes, who exhibited highest bone quality, i.e. rowers and team game players, had calcium intake close to the recommendation (90%), which might have positively affected their present bone mineralisation. It may be inferred that their past nutrition, when staying on training camps, was essentially in accordance with norms.

Much attention has been paid to the effects of physical activity and calcium intake on the bones with emphasis on the synergism of those two environmental factors (35-37), as supported also by own studies. Namely, women who were physically active and consumed calcium according to requirements, had better indices of bone quality than those who did not meet these criteria (cf. Table 6 and Fig. 2).

Conclusions

1. A higher bone mass of ex-athletes compared with untrained women was probably due to a more active lifestyle of the former, apart from their past sport engagement;
2. The present calcium intake by ex-athletes, most of whom followed the recommended values, seems to have contributed to bone mineralisation.
3. After the sport career has been discontinued, bone mass remains stabilised, provided a health–directed lifestyle is maintained.

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