0021-972X/04/$15.00/0
Printed in U.S.A.

The Journal of Clinical Endocrinology & Metabolism 89(9):4383–4387

doi: 10.1210/jc.2003-031865

The Influence of Intensive Physical Exercise on Bone Acquisition in Adolescent Elite Female and Male Artistic Gymnasts

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Physical exercise enhances bone acquisition during adolescence. The aim of the study was to evaluate the influence of intensive physical exercise on bone acquisition in adolescent elite artistic gymnasts. The study included 262 athletes (93 males and 169 females, aged 13–23 yr) participating in the 24th European Championship held in Greece. Bone age compared with chronological age was delayed by 2 yr for females (n = 120) and 1 yr for males (n = 68). For both sexes, the growth chart of bone mineral density (BMD) followed a normal pattern when estimated according to bone age rather than chronological age. For females, BMD was positively correlated with bone age, chronological age, height, body weight, body mass index, body fat, lean body mass, and with age of onset of training, and negatively with duration of exercise and intensity of training (*P* values range from <0.05 to <0.0001). Multiple regression analysis revealed that age of onset of training was the major parameter attenuating the effect of exercise on BMD (*P* < 0.001). The latter was related to the stage of puberty (*P* < 0.05). For males, BMD was correlated positively with bone age, height, body weight, and lean body mass (*P* values range from <0.01 to 0.0001). Multiple regression analysis revealed that the more powerful factor influencing BMD was weight (*P* < 0.01). In conclusion, bone acquisition in adolescents under intensive physical training follows the normal pattern only when estimated according to bone age. The age of onset, the duration, and the intensity of exercise attenuate the bone acquisition, at least in female artistic gymnasts. (*J Clin Endocrinol Metab* 89: 4383–4387, 2004)

BONE MASS DOUBLES between the onset of puberty and early adult life (1). Sex steroids are responsible for the maturation and increase in human skeleton and sexual dimorphism after the onset of puberty (2). Despite the fact that genetic factors considerably influence bone mass, other factors such as nutrition, natural exercise, various diseases and medicines, age of menarche, and normal menstrual cycle contribute positively or negatively to the acquisition of bone mass. Physical exercise increases bone mass in children and adolescents to a greater degree than in adults (3). In athletes, most reports refer to a small number of adults or to small to medium levels of exercise (4–7). There are few reports dealing with the effect on bone acquisition of high-level physical exercise, especially in artistic gymnasts (AG) (8). The aim of this study was to evaluate the effect of continuous and intensive physical exercise on bone acquisition in elite adolescent AG.

Subjects and Methods

The study included 262 athletes from 44 European countries, 93 boys and 169 girls, aged 13 to 23 yr, who participated in the 24th European Championship of Artistic Gymnasts held in Patras, Greece in April 2002. The study was conducted under the authorization of the International Federation of Gymnastics (F.I.G.) and the European Union of Gymnastics. Informed consent was obtained in accordance with article 7 of the medical organization of F.I.G. competitions, and all athletes participated voluntarily.

The protocol is presented in detail elsewhere (9). Briefly, it included noninvasive clinical and laboratory determinations as well as the completion of a questionnaire. Clinical evaluation included measurement of height, weight, and determination of puberty stages according to Tanner *et al.* (10). Breast and pubic hair development in females were estimated by A.T., and pubic hair development in males was assessed by K.B.M. Testicular volume was recorded as the mean value of both testes. Laboratory determinations included 1) calculation of body composition with the use of portable instrument (Futrex 5000A; Futrex, Inc., Gaithersburg, MD). 2) Bone age was determined according to Greulich-Pyle standards from radiographs of left hand and wrist (11). Complete skeletal maturation was considered to have been reached when the bone age was greater than 16 yr for girls and 18 yr for boys. 3) Measurement of bone mineral density (BMD) in grams per centimeter squared with the use of double energy absorptiometry of x-ray (Osteoview; Medilink, Carnon, France) in the distal scanning site (10%) of the dominant forearm. The distal site covers a region that is defined as 24 mm in length from the place where the distance between radius and ulna is 8 mm (12). Quality control was performed in 25 consecutive measurements using a polyester phantom. The coefficient of variation was 1%. The athletes completed a questionnaire concerning personal data (age of menarche, number of menstrual cycles per year, age of onset of training, and intensity of training, *i.e.* hours of exercise/week, number of participations in international championships per year) and family data (age of mother's and sisters' menarche). Duration of exercise was considered the

First Published Online August 24, 2004

Abbreviations: AG, Artistic gymnasts; BMD, bone mineral density; BMI, body mass index.

JCEM is published monthly by The Endocrine Society (http://www.endo-society.org), the foremost professional society serving the endocrine community.

time in years from the age of onset of training to the age at the time of examination.

Statistical analysis

Data were analyzed using SPSS for Windows (version 8.0; SPSS Inc., Chicago, IL). For the investigation of BMD associations with other parameters, the Spearman rank correlation was used. The one-way ANOVA was applied to compare means of BMD among Tanner stages. Paired *t* test was used to compare the bone and chronological age of subjects. Based on the results of the preceding univariate analyses, a multiple regression analysis was performed to identify predictors of BMD. Statistical significance was set at $P \leq 0.05$.

Results

All athletes participating in the study were Caucasians. In males, bone age was estimated in 82 of 93 subjects. There were 68 male athletes with bone age equal or younger than 18 yr. From 138 of 169 females who had bone age estimation, 120 had bone age equal or younger than 16 yr. The anthropometric parameters and the derived data of the athletes are presented in Table 1.

In females, the mean bone age (13 ± 1.5 yr) was delayed compared with mean chronological age (15 ± 1.5 yr) by 2 yr ($P < 0.05$). There was a positive correlation of BMD with bone age, chronological age, height, weight, body mass index (BMI), body fat, lean body mass, and the age of onset of training, and a negative correlation with the duration and intensity of exercise ($P < 0.05$–0.0001) (Table 2). Using the model of multiple regression analysis among the parameters that correlate with BMD revealed that the more powerful factor influencing BMD was the age of onset of training ($P <$ 0.001; b, 0.466; t, 3.964; r^2, 0.647), *i.e.* the earlier the age of onset of exercise, the worse the effect on bone acquisition. This is more clearly seen when the similar parameter, the duration of exercise, is considered ($P < 0.001$; b, −0.701; t, −4.010; r^2, 0.659) instead of age of onset.

The changes of BMD according to bone age and chronological age are presented in Fig. 1A. A linear increase of BMD was observed that displays a jump in the bone age of 12 yr. The curve obtained according to bone age had higher slope (Fig. 1B) and was similar to the curve of normal pattern, in contrast to the curve of BMD obtained according to chronological age. Mean BMD (grams per centimeter squared) progressively increased (*P*, 0.033; F, 2.851) in Tanner stages of breast development I–V (I, 0.347 ± 0.07; II, 0.427 ± 0.15; III, 0.498 ± 0.14; IV, 0.490 ± 0.15; V, 0.630 ± 0.09) (Fig. 2). The mean age of menarche (15 ± 1.5 yr, n = 60) was delayed compared with their mothers (14.0 ± 1.6 yr, n = 42) and sisters (13.9 ± 1.5 yr, n = 22) and was more pronounced in the latter ($P < 0.01$). No effect in BMD was found according to Tanner stages of pubic hair development or to the age of menarche. Normal menstrual cycles were reported in 17 of 25 girls (68%) with bone age lese than 16 yr, and 8 of 12 (67%) with bone age more than 16 yr.

In males, the mean bone age (16 ± 1.5 yr) was delayed compared with mean chronological age (17 ± 1.0 yr) by 1 yr ($P < 0.05$). There was a positive correlation of BMD with bone age, height, weight, BMI, and lean body mass ($P < 0.05$–0.0001) (Table 2). Multiple regression analysis revealed that the more powerful factor influencing BMD was weight ($P <$ 0.01; b, 0.873; t, 2.219; r^2, 0.139). The changes of BMD according to bone age and chronological age are presented in Fig. 3A. A linear increase of BMD was observed, and the curve according to bone age had higher slope (Fig. 3B) and was comparable to the curve of normal pattern. This was not the case for the curve of BMD obtained according to chronological age. We did not observe any significant differences in BMD values according to the Tanner stages of pubic hair development or to the volume of testes.

Finally, when the range of measured values of BMD was

TABLE 1. Anthropometric parameters of high-level adolescent AG who had not completed their bone maturation

	Females bone age < 16 yr (n = 120)	Males bone age < 18 yr (n = 68)
Chronological age (yr)	15 ± 1.5	17 ± 1.0
Bone age (yr)	13 ± 1.5	16 ± 1.5
Height (cm)	151 ± 7	167 ± 6
Weight (kg)	43 ± 7	59 ± 6.5
BMI (kg/m^2)	18.6 ± 1.6	21.1 ± 1.5
Body fat (kg)	7.9 ± 2.3	6.1 ± 3.0
Lean body mass (kg)	33.7 ± 4.7	52.5 ± 5.5
BMD (g/cm^2)	0.466 ± 0.147	0.689 ± 0.115
Age onset of training (yr)	6.3 ± 2.3	7.5 ± 2.1
Duration of exercise (yr)	9.0 ± 2.2	9.5 ± 2.3
Intensity of training (h/wk)	30 ± 9	27 ± 6
No. of times of participation in international championships	7 ± 4	8 ± 3

TABLE 2. Correlations between bone density and anthropometric parameters in female and male adolescent elite AG who had not completed their bone maturation

	Females bone age < 16 yr (n = 120)	Males bone age < 18 yr (n = 68)
Chronological age	r = 0.238, $P < 0.05$	N.S.
Bone age	r = 0.510, $P < 0.0001$	r = 0.435, $P < 0.0001$
Height	r = 0.438, $P < 0.0001$	r = 0.379, $P < 0.01$
Weight	r = 0.519, $P < 0.0001$	r = 0.471, $P < 0.0001$
BMI	r = 0.616, $P < 0.001$	r = 0.316, $P < 0.05$
Lean body mass	r = 0.465, $P < 0.001$	r = 0.444, $P < 0.0001$
Body fat	r = 0.408, $P < 0.001$	N.S.
Duration of exercise	r = −0.355, $P < 0.01$	N.S.
Age of onset of training	r = 0.538, $P < 0.001$	N.S.
Intensity of exercise	r = −0.531, $P < 0.0001$	N.S.

N.S., Not significant.

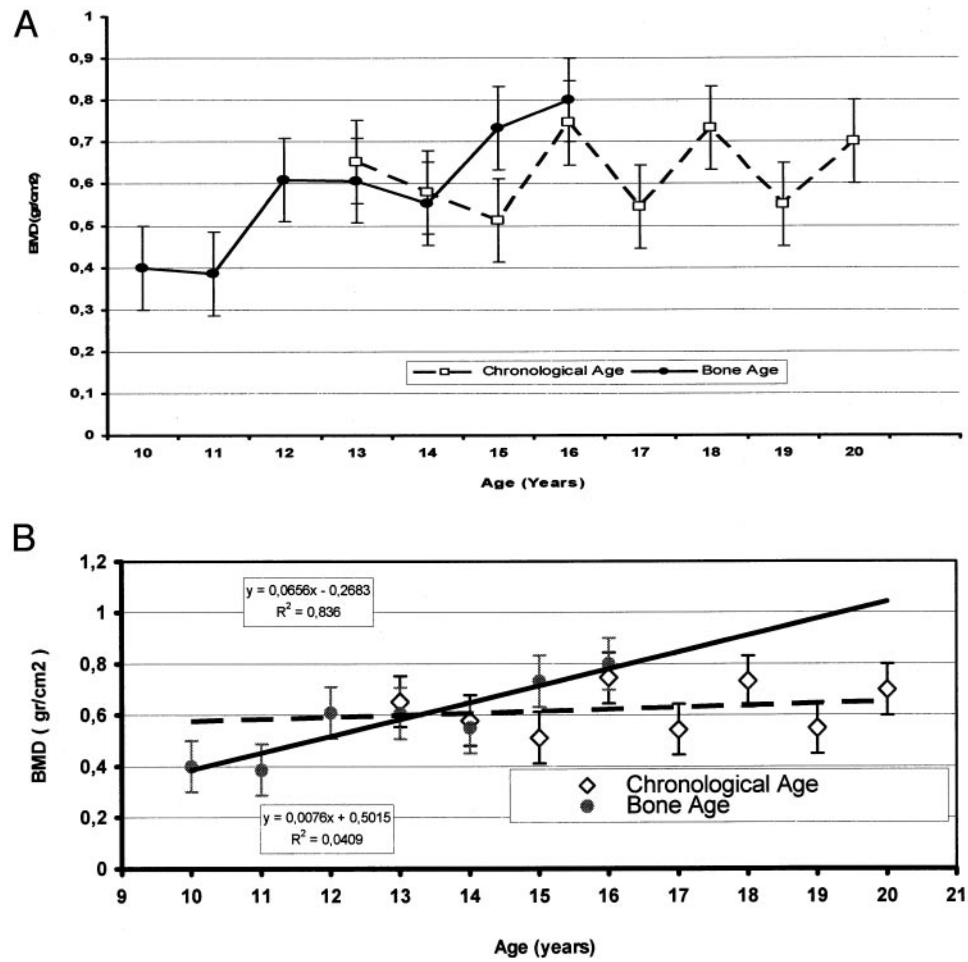

FIG. 1. The increase of BMD (mean ± SD values) in high-level adolescent female AG according to bone age and chronological age (n = 120). A, Numerical values; B, same data expressed as least-squares equations.

plotted according to bone age (males: bone age < 18 yr, minimum of 0.46 to maximum of 0.98 g/cm^2; females: bone age < 16 yr, minimum of 0.21 to maximum of 0.88 g/cm^2), these values were clearly above the corresponding reference levels for normal population (males, 0.33–0.47 g/cm^2; females, 0.31–0.39 g/cm^2), applying the same technique (double energy absorptiometry of x-ray) (13).

Discussion

The configuration of bone mass is influenced by genetic as well as by environmental factors such as physical exercise, nutrition, and body mass (14, 15). Sex steroids and particularly estrogens are fundamental factors for normal growth, configuration of peak bone mass, and conservation of bone mass (2). Bone mass, which is shaped during puberty, appears to play an important role in prevention of fractures in adult life (16). Environmental factors such as physical activity promote the increase in bone mass during puberty even more (17). The positive effect of physical training is particularly obvious in elite athletes and in sports of severe mechanical force such as artistic gymnastics. Artistic gymnastics constitutes a type of exercise with intense mechanical load in the upper and lower limps and in the trunk and is known to exert a beneficial effect on BMD both in adolescent and adult athletes (18–20).

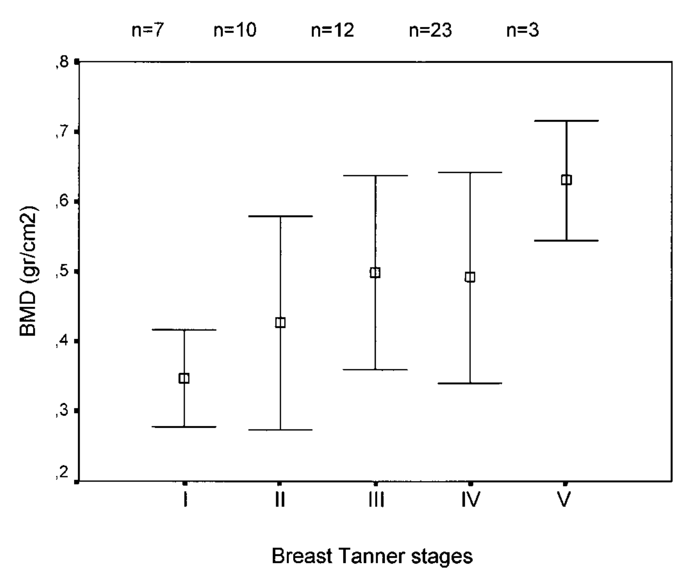

FIG. 2. The increase of BMD (mean ± SD values) in high-level adolescent female AG according to the Tanner stages of breast development (ANOVA, $P < 0.05$).

The cohort of athletes in our study represents a particular group of interest because they are athletes at highly competitive levels who began training at a young age and con-

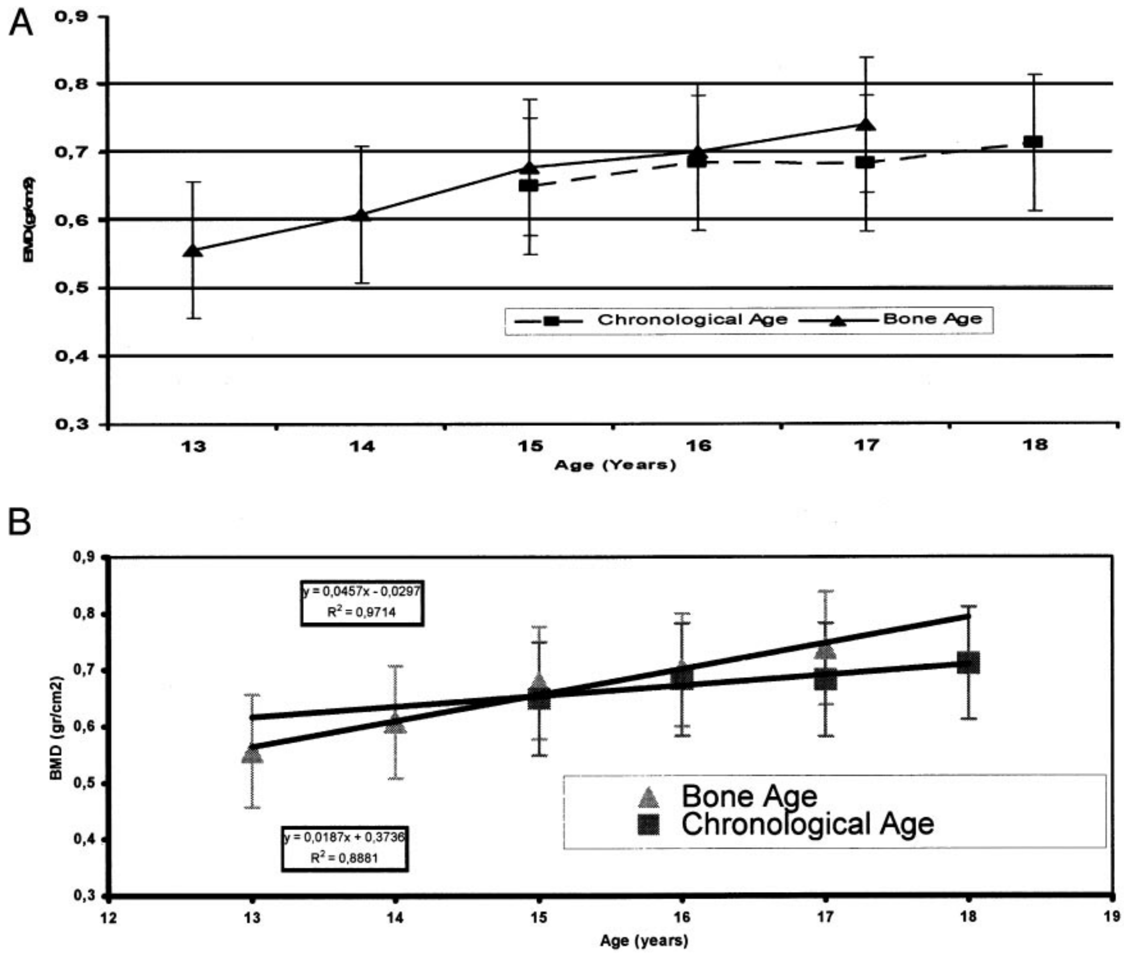

FIG. 3. The increase of BMD (mean ± SD values) in high-level adolescent male AG according to bone age and chronological age (n = 68). A, Numerical values; B, same data expressed as least-squares equations.

tinued their intensive exercise throughout puberty. The intensity of exercise and consequently the mechanical load is at least double that reported until now. Bone age delay in both males and females was more pronounced in the latter. We and others have previously shown that the development of puberty in rhythmic gymnasts follows the bone age rather than the chronological age (9, 19, 21). Low body weight and low body fat reflect an energy deficit, evident in AG, as a consequence of intensive physical training (high energy output) and low caloric diet (low energy input). Indeed, AG are exposed to a significant energy drain occurring early in preadolescence and are highly motivated to maintain low body weights due to their sport's requirements for a thin somatotype. The delay in bone age in our study may be attributed to low energy input as judged by the measured low body fat and to the continuous and severe somatic and psychological load. It is known that both intensive physical training and psychological stress during childhood and adolescence lead to a delay in skeletal maturation (22), whereas the progression of puberty follows the bone age rather than the chronological age (9).

During adolescence, bone mass increases according to chronological age, and this increase becomes evident 2 yr earlier in girls than in boys, because girls enter puberty much earlier (2, 21). In our study we found that the increase in BMD was observed clearly when based on the bone age curve, although this increase was not observed from the chronological age curve. The latter can be explained by the fact that each point of the chronological age curve represents the mean of BMD values obtained from individuals of different bone age. This observation was more pronounced in females due to a greater delay of bone age. Early onset and high intensity of training have been reported to negatively influence the sex hormone-dependent acquisition of bone mass (23). Bone acquisition, in the female athletes studied here, was proportional to development of puberty according to Tanner stages of breast development, which reflects the increasing biological activity of estrogens (24). The reported normal menstrual cycles in the majority of examined athletes imply the normal biological action of estrogens.

In males, the changes in bone acquisition were not related to testicular volume. It should be noted that most athletes had testicular volume greater than 15 ml, suggesting almost complete testicular maturation. It is reasonable, therefore, to assume that the exerted biological action of testosterone on the bones was uninhibited by the chronic and intensive exercise.

In females, the strong negative influence of the early onset of training on bone acquisition might indicate the vulnerability of bone metabolism before the onset of sex steroid production at puberty. However, the duration of exercise on bone acquisition overall cannot be ruled out. Indeed, as judged by the range of measured BMD, which is clearly above the corresponding reported levels in sedentary matched normal population (13), the excess mechanical load to which these athletes are exposed from a young age exerts its beneficial effect on bone acquisition, leading to a positive net effect.

The acquisition of bone mass for both sexes was related positively with height, BMI, lean body mass, body fat (only for females), and weight. The last was the most powerful factor in males. This is consonant with the observation that weight is strongly related to bone mass. These results are similar with reported data for normal population and for athletes exposed to exercise of light to medium intensity (19, 25–27). The relation with body fat is attributed to increased estrogenic activity resulting from the action of fat on estrogen production (27).

Finally, the delay of bone age in both male and female athletes provides indirect evidence that, at least in adolescent elite AG as a cohort, the use of anabolic steroid drugs to enhance their strength is probably not practiced. The role of these drugs in the promotion of bone age is well known (28).

In conclusion, bone acquisition in children and adolescents who are continuously and intensively trained from early ages follows the normal pattern only when estimated according to bone age and not to chronological age. The early onset of training, the continuous and intensive exercise, as well as the duration of exercise negatively affect bone acquisition, at least in adolescent female AG.

Acknowledgments

We express our grateful thanks to Mr. D. Dimitropoulos, President of the Greek Federation of Gymnastics, for the facilitation and support that were provided to us; Dr. G. Iconomou for his substantial help to statistical analysis; and the students of the Medical Department of the University of Patras for their contribution in data collection.

Received October 27, 2003. Accepted March 28, 2004.

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