The Influence of Intense Ballet Training on Trabecular Bone Mass, Hormone Status, and Gonadotropin Structure in Young Women

ROSSELLA VALENTINO, SILVIA SAVASTANO, ANTONIO PASQUALE TOMMASIELLI, GIOVANNI D’AMORE, MAURIZIO DORATO, AND GAETANO LOMBARDI

Consiglio Nazionale delle Richerche (R.V.), Experimental Endocrinology and Oncology Center (CEOS), Department of Cellular and Molecular Biology and Pathology; Federico II University Medical School, 80131 Naples; Chair of Endocrinology (S.S., M.D., G.L.), Department of Molecular and Clinical Endocrinology and Oncology; Federico II University Medical School, 80131 Naples; Group for Studies in Endocrinology (A.P.T., G.D.), 80131 Naples, Italy

A cross-sectional study on young dancers and exdancers was performed to evaluate the effects of intense weight-bearing exercise and dietary restriction, started during puberty, on bone mineral density (BMD), menarche age, menstrual function, and gonadotropin structure. Twenty current dancers (group 1) and 9 exdancers (group 2) were compared with a control group of 30 age-matched, regularly cycling women. Body weight, body mass index, total daily caloric intake, and nutritional markers were significantly lower (*P* < 0.05) in groups 1 and 2 than in controls. Using Quantitative Computed Tomography for the BMD evaluation, 12 dancers and 5 exdancers had Z-scores less than 2.5 SD below the mean of the controls; whereas, in 6 dancers and in 2 exdancers, BMD was between 1 and 2.5 SD. Groups 1 and 2 had a delay of menarche, which correlated positively with years of dance before menarche (*r* = 0.8; *P* < 0.001). Dancers had low levels and altered pulsatility of circulating gonadotropins, which improved after GnRH stimulation.

In conclusion, ballet training performed by dancers during puberty, dietary restriction, and low body mass index can all be associated with reduction in BMD and altered gonadotropin isoforms, with subsequent delay of menarche, menstrual dysfunctions, and insufficient peak bone mass. A longitudinal study must be conducted to confirm the persistence of low lumbar spine bone density in adult age.

**Observational and Clinical** data strongly indicate that intense ballet training during adolescence, especially when associated with weight loss, undernutrition, and low body mass index (BMI), can cause menstrual abnormalities, with neuroendocrine dysfunction and low bone mineral density (BMD) (1–6). In particular, dysfunctions in the hypothalamic–pituitary–ovary axis and amenorrhea are common features in weight-loss and eating disorders, probably related to hypothalamic changes in pulsatile secretion of CRH and GnRH (5–12). In malnutrition, in fact, abnormalities in the central regulation of the GnRH pulse-generation system have been described (7, 10–12), with reduced gonadotropin pulsatility associated with an age-inappropriate gonadotropin secretion pattern, typical of prepuberty (6). In patients with anorexia nervosa, it has been previously observed that modification in gonadotropin microheterogeneity is a possible cause of hypothalamic amenorrhea, which can reverse after acute administration of GnRH and normalization of the patients’ eating habits (11, 12).

It is well known that sedentary individuals generally have lower bone mass than physically active ones, and that moderate exercise can improve skeletal mass (13). Conversely, a reduction in bone mass along with a potential risk of osteoporosis have been reported in long-distance women runners or athletes who perform chronically strenuous aerobic exercise, especially when combined with caloric restriction (2, 3). In this context, dance training and the particular lifestyle of ballet dancers have been reported to exert different effects at different skeletal sites (1), although the long-term effects at weight-bearing sites are not evident in exdancers (4, 14, 15).

The aim of this study was to evaluate cross-sectionally in young female dancers, the association of low BMD of lumbar spine, and altered gonadotropin glycosylation with multiple risk factors (such as dietary habit, extreme thinness, menstrual dysfunction, and intense ballet training during skeletal development), checking also, in young adult exdancers, the possible consequence of inadequate peak bone mass accumulation during growth.

**Subjects and Methods**

**Experimental subjects**

The daily dietary intake was assessed by 7-d diet records, with the distribution of 200 special self-administered, semiquantitative, validated food-frequency questionnaires, according to Badart-Smook, Beaton, et al. (16, 17). Young dancers (n = 50), exdancers (n = 50), and controls (n = 100), with a similar socioeconomic status, were selected from professional ballet schools and universities. The questionnaires concerned age, height, weight, duration of training, intensity of physical exercise per week, age at menarche, menstrual regularity, and dietary habits. The controls were all university students, who volunteered to participate, selected to represent regularly menstruating age-matched women who exercised fewer than 2 h per week; they were representative of the social class distribution of the population from which dancers usually derive. A total of 144 subjects (72%) responded to the 200 questionnaires administered; of the respondents, 48 were dancers (33.3%), 20 were exdancers (13.9%), and 76 were controls (52.8%).

Abbreviations: AP, Alkaline phosphatase; BMD, bone mineral density; BMI, body mass index; CV, coefficient of variation; F, cortisol; FEI, free E index; IRMA, immunoradiometric assay.
Thirty-six women (5 dancers, 8 exdancers, and 23 controls) were enrolled in this cross-sectional study, for practical consideration (such as money availability for the research), only 59 young women [20 ballet dancers (group 1; mean age, 21.5 ± 3.7 yr), 9 exdancers (group 2; mean age, 22.3 ± 1.8 yr), and 30 age-matched normally cycling controls (mean age, 22.5 ± 1.5 yr)] in all subjects, BMI was calculated as kg/m^2 (normal ranges for females, 18–23 kg/m^2).

Informed consent to participate in this study was given by all the women involved, and by the parents of dancers who were not yet 18 yr old. Moreover, the study was carried out in accordance with the ethical standards laid down in the appropriate version of the 1964 Declaration of Helsinki, and approval was obtained from the Federico II University Institutional Review Board.

All dancers, and exdancers when they were dancing, had a dance training consisting of more than 10 h of exercise per week (mean, 13 ± 2 h), starting in preadolescence (mean age, 7.3 ± 1.6 yr) and continuing for at least 10 yr. The 9 exdancers had reduced their intense physical activity at the age of about 19 yr (18 ± 1.7 yr), 2.8 ± 1.5 yr before this study, basically when they increased the study engagement or began to attend university (all commitments incompatible with an intense ballet training). During our study, the exdancers performed a mean of 3 ± 3 h of exercise/week, in particular: running, generic gymnastic training, jazz, or modern dance. The control group performed, generally, less than 2 h of exercise/week (0.3 ± 2; from sedentary life to (for a few) recreational running or generic gymnastic training). Among the 20 dancers (group 1), 16 had menstrual abnormalities (14 had oligomenorrhea and 2 amenorrhea), whereas 4 were regularly cycling, among the 9 exdancers (group 2), 3 had oligomenorrhea, whereas 6 were regularly cycling. All controls were regularly menstruating.

Materials and methods

Blood samples were collected between 0800 and 1000 h, in fasting conditions, in the early follicular phase (on d 4–6) or on an arbitrary day in patients with amenorrhea. The samples were centrifuged, and sera were separated and stored frozen at −20°C for a maximum of 3 months, until RIA and immunoradiometric assay (IRMA), which were performed in duplicate and within the same assay for each hormone, to avoid interassay variations. The mean of intraassay coefficients of variation (CVs) of all hormones assayed by the RIA method was 5.4%; whereas, for the IRMA method, it was 2.9%. In particular, for FSH and LH, assayed by the IRMA method (CIS Diagnostica, Tronzano Vercellos-Torino, Italy; ICN Biomedicals, Inc., Costa Mesa, CA; Diagnostic Systems Laboratories, Inc., Webster, TX), the intraassay CVs were 3.5% and 1.6%, respectively. Estrogens (E2), PRL, SHBG, dehydroepiandrosterone sulfate, cortisol (C), T4, TSH, T3-binding globulin (TBG), and IGF-1 were assayed in basal conditions, using commercial RIA and IRMA kits (CIS Diagnostics, Tronzano Vercellos-Torino; RADM, Pomezia-Roma, Italy; ICN Biomedicals, Inc., Costa Mesa, CA; Diagnostic Systems Laboratories, Inc., Webster, TX). The free E index (FEI) was calculated as E2/SHBG.

FSH and LH levels were assayed in basal conditions and after a stimulation test in the early follicular phase, (d 4–6) or on an arbitrary day (2; from sedentary life to (for a few) recreational running or generic gymnastic training). Among the 20 dancers (group 1), 16 had menstrual abnormalities (14 had oligomenorrhea and 2 amenorrhea), whereas 4 were regularly cycling, among the 9 exdancers (group 2), 3 had oligomenorrhea, whereas 6 were regularly cycling. All controls were regularly menstruating.

BMD was measured by spiral quantitative computed tomography, equipped for bone mineral densitometry, using the same scanner (PQS CT; Picker Italia Medical Systems, SpA, Italy) for the lumbar spine examination at L2-L4 levels (19–21). The results were averaged and expressed as milligrams of KxHPO4 per cubic centimeter (see Table 5). All BMD values were also expressed as Z-scores, that better reflect the BMD, considering the young age of the subjects. All values were adjusted for the distribution of age alone, and age and weight together, based on linear regression analyses of an Italian young healthy female population and of our 30 age-matched controls. The Z-score was derived by calculating the difference between the bone densities observed and those predicted, divided by the SD. The CV of quantitative computed tomography was approximately 2%, expression of long-term precision for mineral content, obtained in excised vertebrae in a phantom simulating the human torso. Moreover, for the evaluation of bone turnover markers, in all subjects, we evaluated serum and urinary calcium by atomic absorption spectrophotometer. An Eastman Kodak Co. (Rochester, NY) Autoanalyzer assayed alkaline phosphatase (AP) in sera. The total urinary excretion of calcium and hydroxyproline were expressed in the 24 h, and hydroxyproline was measured by Hypronostic (Organon Teknika, Bexlot, Holland) after a 5-d special collagen-free diet.

Intact PTH and osteocalcin were assayed in serum, in basal conditions, using commercial RIA and IRMA kits (ICN Biomedicals, Inc., Costa Mesa, CA, and Diagnostic Systems Laboratories, Inc.).

Statistical analysis

All data are expressed as mean ± sn.

Statistical differences were assessed by one-way ANOVA, followed by the Student-Newman-Keuls’ test. The confidence interval was set at 95%, and the significance level used was P < 0.05 (two sides).

Significant relationships between variables were analyzed using Pearson’s product-moment correlation.

Results

The 20 ballet dancers enrolled in this cross-sectional study (group 1) and the 9 exdancers (group 2) had significant low body weight and BMI, compared with the control group (P < 0.05). BMI in group 1 was also significantly lower than in group 2 (P < 0.05) (Table1).

In both groups 1 and 2, there was a slight delay in age at menarche (Table 1). In only group 1, there was a strong positive correlation between age at menarche and years of dance before menarche (15.1 ± 0.8 and 7.4 ± 1.8 yr, respectively, r = 0.8; P < 0.001) (see Fig. 1), and a weak correlation between age at which ballet was started (r = −0.6; P < 0.05) and cumulative years of ballet (r = 0.5; P < 0.05).

The data obtained from our self-administered dietary record methodology about eating habits showed that all subjects habitually drank moderate amounts of coffee, and none

| TABLE 1. Physical and historical data on active young women ballet dancers (group 1), retired ballet dancers (group 2) and sex- and age-matched controls, presented as group means, with SD and significant differences by ANOVA and Student-Newman-Keuls test |
|-----------------|-----------------|-----------------|-----------------|
| Group 1         | Group 2         | Normal controls |
| Age (yr)        | 21.5 ± 3.7      | 22.3 ± 1.8      | 22.5 ± 1.5      |
| Height (cm)     | 163 ± 2         | 164 ± 3         | 163 ± 4         |
| Weight (kg)     | 52.5 ± 2.9      | 53.6 ± 3.0      | 56.9 ± 3.5      |
| BMI (kg/m²)     | 18.1 ± 1.1      | 19.1 ± 1.6      | 22.1 ± 1.1      |
| Age at menarche | 15.1 ± 0.8      | 14.0 ± 1.2      | 13.2 ± 1.1      |
| Age at starting dance (yr) | 7.90 ± 0.79   | 8.00 ± 0.87    |                |
| Hours of exercise (per week) | 13 ± 2.9       | 8 ± 3.0        | 0.3 ± 2         |

P < 0.05, groups versus the normal controls.

P < 0.05, group 1 vs. group 2.
smoked or drank alcohol chronically or took nutrition supplemen-
tations such as vitamins, calcium, or other minerals. The lowest daily calorie intake was evidenced in group 1; although, in group 2, the caloric intake was still lower than in the control group (Table 2). Some nutritional markers were significantly lower in both groups 1 and 2, particularly IGF-1, SHBG, and TBG; whereas iron levels, ferritin, and albumin were lower only in group 1, when compared with the control group (P < 0.05) (Table 2), but not enough for an iron deficiency diagnosis. This evidence suggested that the exdancers may have changed, but not entirely corrected, their eating habits.

Gonadotropins were lower in group 1 than in group 2 and in controls, with lower E levels (P < 0.05) in group 1 than in controls, still lower in group 2, and low FEI in group 1 (expression of peripheral E activity) (Table 3). Conversely, F plasma levels were significantly higher than in controls only in group 1 (P < 0.05) (Table 3).

In basal conditions and after the GnRH stimulation test, basal and absolute peak values (time, 45–60) of circulating gonadotropin were significantly lower in group 1 than in controls (P < 0.05) (Table 4), with a basal % FSH-UB, after Con-A, higher in groups 1 and 2 than in controls (P < 0.05), and significantly lower in all groups, when compared with basal values (P < 0.05) after acute GnRH testing (Table 4). In basal conditions, % LH-UB was higher in group 1 than in group 2 and controls (P < 0.05), with a significant reduction after acute GnRH testing in all groups, when compared with basal values (P < 0.05) (Table 4).

BMD values on lumbar spine (L2–L4), a weight-bearing site, were significantly lower in groups 1 and 2 (P < 0.05) than in controls (Table 5). Overall, 17 women (12 dancers in group 1, and 5 exdancers in group 2) had Z-scores of lumbar spine less than 2.5 sd below the mean of our age-matched controls and an Italian female general population, whereas 8 (6 women in group 1, and 2 women in group 2) showed BMD levels at the lower limit of the normal range (Z-score between 1 and 2 sd); only 2 dancers and 2 exdancers presented BMD in the normal range for their age. All biochemical and hormonal bone turnover markers, such as AP, total serum, and urinary calcium, urinary hydroxyproline, PTH, and osteocalcin, were in the normal range for their age. All biochemical and hormonal bone turnover markers, such as AP, total serum, and urinary calcium, urinary hydroxyproline, PTH, and osteocalcin, were in the normal range for their age. All biochemical and hormonal bone turnover markers, such as AP, total serum, and urinary calcium, urinary hydroxyproline, PTH, and osteocalcin, were in the normal range for their age. All biochemical and hormonal bone turnover markers, such as AP, total serum, and urinary calcium, urinary hydroxyproline, PTH, and osteocalcin, were in the normal range for their age.
TABLE 4. Baseline and maximum peak of FSH and LH (time, 45–60) after GnRH test (mIU/ml) and baseline and minimum value after concanavalin A-sepharose (% UB), in ballet dancers (group 1) and exdancers (group 2), as compared with normal controls and expressed as mean ± sd, with significance by ANOVA and Student-Newman-Keuls test.

<table>
<thead>
<tr>
<th></th>
<th>Group 1 (20)</th>
<th>Group 2 (9)</th>
<th>NC (30)</th>
<th>Group 1 (20)</th>
<th>Group 2 (9)</th>
<th>NC (30)</th>
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<tbody>
<tr>
<td>Basal value</td>
<td>2.7 ± 0.9a</td>
<td>4.6 ± 1.3</td>
<td>5.5 ± 1.5</td>
<td>3.6 ± 0.8a</td>
<td>4.7 ± 1.3</td>
<td>6.3 ± 2.8</td>
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<tr>
<td>Maximum peak</td>
<td>9.6 ± 1.3a</td>
<td>11.2 ± 2.9</td>
<td>13.5 ± 3.9</td>
<td>6.2 ± 2.1a</td>
<td>10.8 ± 5a</td>
<td>16.5 ± 5</td>
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<tr>
<td>% UB basal value</td>
<td>94.5 ± 4a</td>
<td>89 ± 5a</td>
<td>83 ± 8</td>
<td>67 ± 16a,b</td>
<td>20.5 ± 9</td>
<td>20 ± 6</td>
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<tr>
<td>% UB minimum value</td>
<td>59.5 ± 13c</td>
<td>62.5 ± 11c</td>
<td>63 ± 13c</td>
<td>22.5 ± 14c</td>
<td>12.5 ± 2.2c</td>
<td>12 ± 3c</td>
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</table>

a P < 0.05, groups vs. the normal controls (NC).
b P < 0.05, group 1 vs. group 2.
c P < 0.05, vs. baseline.

TABLE 5. Hormonal, biochemical bone turnover markers and BMD in ballet dancers (group 1) and exdancers (group 2), as compared with normal controls and expressed as mean ± sd, with significance by ANOVA and Student-Newman-Keuls test.

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<tr>
<th>Markers with normal ranges</th>
<th>Group 1 (20)</th>
<th>Group 2 (9)</th>
<th>Normal controls (30)</th>
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<tr>
<td>BMD (lumbar spine, L2–L4)</td>
<td>97 ± 14a</td>
<td>100 ± 12a</td>
<td>176 ± 26</td>
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<tr>
<td>PTH (10–65 ng/liter)</td>
<td>33 ± 3.5</td>
<td>34.5 ± 3</td>
<td>35 ± 5</td>
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<td>Osteocalcin (1–15 ng/ml)</td>
<td>7.2 ± 1.8</td>
<td>7.7 ± 3</td>
<td>7.2 ± 3</td>
</tr>
<tr>
<td>ur. Ca (2.5–7.5 mmol/24 h)</td>
<td>3.8 ± 0.3</td>
<td>5.1 ± 0.3</td>
<td>5.6 ± 0.5</td>
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<tr>
<td>Hydroxyproline (mg/24 h)</td>
<td>18.4 ± 1.1</td>
<td>20.6 ± 0.8</td>
<td>21 ± 0.5</td>
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<tr>
<td>ur. Creatinine (0.7–1.2 g/24 h)</td>
<td>0.83 ± 0.04a</td>
<td>0.89 ± 0.06a</td>
<td>0.95 ± 0.04</td>
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<tr>
<td>AP (98–275 U/liter)</td>
<td>164 ± 15</td>
<td>163 ± 16</td>
<td>173 ± 23</td>
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BMD is expressed as mg of K$_2$HPO$_4$ per cm$^2$. Urinary hydroxyproline, normal ranges 6–22 mg/24 h.
a P < 0.05, groups vs. the normal controls.
b P < 0.05, group 1 vs. group 2.

larly on weight-bearing sites, related to the age at which heavy training begins and total years of ballet (1, 25–27). Usually, exercise has a positive effect on cortical bone (femoral neck), because it stimulates bone formation (1, 13, 27); however, it has also a negative effect on trabecular bone (lumbar spine), because of the influence of exercise on menstrual dysregulations through the action of E and progesterone (22–24, 28). In our dancers, we observed a significant decrease in trabecular bone density, compared with controls, along with significant increased F levels, expression of stress and HPA activation (7, 8), and significant variations in FSH and LH basal and stimulated secretion, with low E2 and FEI. These alterations, leading to a prolonged prepubertal state, help to maintain a slim body, considered ideal in classical ballet. Moreover, in group 1, we observed low levels of other plasma glycoproteins, such as TBG and SHBG, all probably influenced by hormonal and nutritional factors, as previously reported (29, 30). We previously reported that anorexia nervosa is one of the possible clinical conditions characterized by altered gonadotropin glycosylation (11, 12), improved after exogenous GnRH acute administration, thus suggesting abnormalities in endogenous GnRH pulse generator (2, 12, 31, 32). In the present study, also dancers, who frequently presented oligomenorrhea, had a dysregulation in the hypothalamic-pituitary-ovary axis, with altered microheterogeneity of gonadotropin isoforms similar to that observed in anorectic patients, with a significant increase (P < 0.05) in FSH and LH-UB (expression of qualitative changes in both circulating FSH and LH levels) (Table 4), and with the same improvement after the GnRH acute test. Conversely, in group 2, the reduction or cessation of strenuous exercise and the changes in eating habits, with subsequent weight gain, restoring GnRH pulsatility, improved the gonadotropin mi-

croheterogeneity, leading to the resumption of the menstrual function. The insufficient peak bone mass obtained during puberty can cause a persistent low BMD in exdancers that must be confirmed during the adult age, in a longitudinal study, to avoid risk of pathological fractures.

In conclusion, our data suggest that a low energy intake, combined with intense physical exercise in puberty, could be associated with negative effects on the reproductive and skeletal systems in ballet dancers. In particular, the alteration of microheterogeneity of gonadotropin isoforms, with subsequent menstrual dysfunction and low E plasma levels, along with an insufficient peak bone mass during puberty, may be involved in BMD loss, particularly at the trabecular bone level. Because it is impossible in a cross-sectional study to extrapolate relationships between body weight, amount of exercise, and menstrual abnormalities, a prospective and a longitudinal study will be useful to explain why these effects on bone mass are still evident in exdancers without significant reproductive problems and whether this evidence could increase the risk of osteoporosis and stress fractures during adult and old age. The increased awareness of the endocrine-metabolic consequences on BMD in the dance world is crucial to preventing these risks.

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Address all correspondence and requests for reprints to: Dr. Rossella Valentino, CEOS (CNR) Department of Cellular and Molecular Biology and Pathology, via Pansini, 5, 80131 Naples, Italy. E-mail: sisavast@unina.it.

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