The Effects of Nutrition, Puberty and Dancing on Bone Density in Adolescent Ballet Dancers

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Abstract

Ballet dancers have on average a low bone mineral content (BMC), with elevated fracture-risk, low body mass index (BMI) for age (body mass index, kg/m2), low energy intake, and delayed puberty. This study aims at a better understanding of the interactions of these factors, especially with regard to nutrition. During a competition for pre-professional dancers we examined 127 female participants (60 Asians, 67 Caucasians). They averaged 16.7 years of age, started dancing at 5.8 years, and danced 22 hours/week. Assessments were made for BMI, BMC (DXA), and bone mineral apparent density (BMAD) at the lumbar spine and femoral neck, pubertal stage (Tanner score), and nutritional status (EAT-40 questionnaire and a qualitative three-day dietary record). BMI for age was found to be normal in only 42.5% of the dancers, while 15.7% had a more or less severe degree of thinness (12.6% Grade2 and 3.1% Grade 3 thinness). Menarche was late (13.9 years, range 11 to 16.8 years). Food intake, evaluated by number of consumed food portions, was below the recommendations for a normally active population in all food groups except animal proteins, where the intake was more than twice the recommended amount. In this population, with low BMI and intense exercise, BMC was low and associated with nutritional factors; dairy products had a positive and non-dairy proteins a negative influence. A positive correlation between BMAD and years since menarche confirmed the importance of exposure to estrogens and the negative impact of delayed puberty. Because of this and the probable negative influence of a high intake of non-dairy proteins, such as meat, fish, and eggs, and the positive association with a high dairy intake, ballet schools should promote balanced diets and normal weight and should recognize and help dancers avoid eating disorders and delayed puberty caused by extensive dancing and inadequate nutrition.

On average, female ballet dancers have low BMI (body mass index: kg/m2), relatively low bone mineral density (BMD), and an elevated risk of stress fractures.[1] Many teenage dancers demonstrate high energy expenditure, extreme leanness, and delayed puberty. All of these factors influence bone health. Preventive measures for optimal bone health are especially important during adolescence.

Classical ballet dancing is an art form in which aesthetic criteria encourage low BMI. Young dancers often limit their energy intake to maintain a thin body,[2] especially if they are going for a professional career. Furthermore, the energy restriction is often accompanied by a decreased protein and fat intake, as shown by Frusztajer and colleagues.[1] Seventy percent of dancers in the Frusztajer study consumed less than 85% of Recommended Dietary Allowances (RDAs) for calories. Sixty percent were vegetarian and presented very deficient protein intakes. Mineral and vitamin intakes were also often deficient, including calcium and vitamin D, which are indispensable to optimal bone health. Merrilees and associates[3] showed the importance of calcium for optimal BMD in their three-year study of girls aged 15 to 18 years; subjects significantly increased their BMD at the trochanter, femoral neck (FN), and lumbar spine (LS) when their diets were supplemented with dairy products containing a mean of 1,160 mg of calcium per day. In this context it is probable that the restriction of energy intake over the long-term is responsible for growth and health impairment. Low energy intake contributes to health problems such as pubertal delay, irregularities in the menstrual cycle,[4,5] low estrogen, and bone loss. In a case-

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control study comparing teenage ballet dancers and relatively inactive teenagers, the age of menarche in the dancers was delayed by an average of 4 months, and 42% presented with oligomenorrhea.[6]

During the peripubertal years in normal growth there is an asynchrony between the rates of growth in stature and mineral mass accrual, which induces a state of relatively low bone mass. This crucial period, during which the mineralization of bone lags behind the growth rate, lasts 3 to 4 years and is characterized by an increased risk of stress fracture.[7] The increase in BMC occurs two years after menarche.[8] In cases of delayed puberty, maturation of the skeleton is also delayed, and the fracture risk is maintained. These problems are present in adolescent ballet dancers of both sexes.

The primary objective of this cross-sectional study was to examine how dance exposure, pubertal delay, and unbalanced nutrition affect BMAD in pre-professional ballet dancers who are 15 to 17 years old.

Methods

Participants

One hundred and twenty-seven female ballet dancers (out of a total of 190 potential participants) agreed to take part in the study, which was conducted during two consecutive years (2004 and 2005) at the "Prix de Lausanne," an international dance competition for pre-professional student dancers who range in age from 15 to 18 years. Three girls suspected of having anorexia nervosa were identified before the competition by the Prix de Lausanne's health department and eliminated from the study. Sixty-seven of the participants were Caucasian, and 60 were Asian. During the competition each dancer was evaluated by a physician, dietician, and nurse and underwent densitometry. A translator accompanied the dancers when necessary. The study protocol was approved by the University of Lausanne's ethics committee. Written informed consent was obtained from each subject as well as her parents or accompanying teacher.

Diet

Several months before the competition all participants were mailed registration documents accompanied by a letter that explained the study; the letter was translated professionally in the appropriate language (English, French, Russian, Chinese, Japanese, and Korean). The documents consisted of a general health questionnaire including specific data on dancing, and a 3-day standard qualitative dietary record (DR). Participants were instructed that this record must include two week days and one weekend day. An explanatory brochure on how to fill it in was included. Participants were asked to describe precisely all foods and beverages consumed during the 3 days in terms of pre-defined quantitative units of measurement or servings, such as one cup (150 ml), one bowl (200 ml), 1 tablespoon, and so forth. These units were then converted into the portions. (Participants were not required to weigh portions because it was considered unrealistic to impose the responsibility for weighing food on these subjects of varied national and cultural origins. Therefore, we have no data on total energy and nutrient intake.)

The DR was filled out by the dancer at home or at her dance school and returned before the competition. It was reviewed by the dietician during the competition and each dancer was asked to clarify unanswered questions. After the competition each food consumed and reported in the DR was allocated to one of four food categories: non-dairy proteins (meat, fish, and eggs), dairy products, fruits and vegetables, and starchy foods. Tofu was rarely consumed by the Caucasians (only three subjects ate one portion or more per day) or, surprisingly, by the Asians (only nine subjects consumed one portion or more of tofu-based foods per day). Therefore, tofu-based products were included in the meat-fish-egg food group. For total protein intake we combined meat, fish and eggs with dairy products. Grains and legumes belong to the starchy food group according to the Swiss Society of Nutrition,[9] although they contain some proteins (but much less than meat, fish, and eggs and dairy products).

The approximate quantity of foods consumed was noted as portions (or servings), according to the definition of the Swiss Society of Nutrition[9]: 100 to 120 grams of meat, fish, or eggs (or simply 2 eggs) are equivalent to one portion; 120 grams fruits and vegetables are one portion; starchy food, such as 75 to 125 grams of bread, 180 to 300 grams of potatoes, 45 to 75 grams of cereals, pasta, or rice (uncooked) are one portion; dairy products such as 2 dl of milk, 1 yogurt, 30 grams of hard cheese, 60 grams of soft cheese are one portion. The number of portions consumed per day was calculated for each subject after the competition. For example, if a subject drank 100 ml of milk in the morning and had half a yogurt at lunch, this was considered as one portion of dairy product. Then each portion of food consumed according to the DR was allocated to one of the four food categories. This allowed us to count how many portions of each food group were consumed. Once this calculation was completed, the results were compared to the recommendations of the Swiss Society of Nutrition (food pyramid for dietary intake).[9] These recommendations include five portions of fruits and vegetables, three portions of starch, three portions of dairy products, and one portion of meat, fish, or egg per day.

The Eating Attitude Test (EAT-40) is a validated 40-item self-report questionnaire by which participants respond to 40 items on a 5-point Likert-type scale.[10] A score of greater than or equal to 30 is commonly used as a cut-off value for identifying individuals with a strong probability of anorexia nervosa or bulimia.

The physician carried out a physical examination and completed a general health questionnaire with more specific questions about each dancer's training.

Anthropometric Measurements

Weight was measured with an electronic scale to the nearest 0.1 kg. Standing height was measured to the nearest 0.1 cm. Body Mass Index (BMI, kg/m^2) was determined. In adolescents, the reference values for BMI depend on age; therefore, "thinness" was defined and graded according to the method described by Cole and coworkers,[11] which is based on pooled international data for BMI and linked to the World Health Organization's recommended adult cut-off points. This allows for age-dependent classification. Thinness grade 1 corresponds to a BMI less than 18.5 at age 18, thinness grade 2 to a BMI less than 17 at age 18, and thinness grade 3 to a BMI less than 16 at age 18.

Bone Mineral Content Measurements

Bone mineral content (BMC) of the left femoral neck (FN) and lumbar spine (L1-L4) was measured by dual-energy x-ray absorptiometry (DXA: Hologic QDR 4500 C, software version 12.01). The DXA machine was installed in a truck and parked just outside the competition area. Hologic QDR 4500 C did not allow for measuring of the whole body. For this study, three parameters were retained: bone mineral content (BMC), bone mineral height adjusted (BMC height adjusted), and bone mineral apparent density (BMAD). It has been decisively concluded in previous studies that BMC is the most accurate parameter in the growing population. Because of the confounding affect of bone size, several investigators suggest using BMC adjusted for height, especially in children.[12,13] Furthermore, the 2007 International Society for Clinical Densitometry (ISCD) Pediatric Official Positions also suggest adjusting BMC for height.[14] Hence, we used BMC with height adjusted as the primary outcome variable. BMAD represents an empirical method for attempting to adjust for differences in the third dimension that BMD does capture,[13] and is used in this study as a parameter of mineralization independent of bone size. BMD is affected by the subject's size and is misleading during the adolescent growth period.[15,16] It is not recommended for use in studies with growing individuals, as bone size cannot be assumed to be constant, which is why we did not use it in this study.[15]

As advocated by Carter and coworkers,[17] LS BMAD was calculated with the formula LS BMAD [g/cm^3] = (BMC [g]/area [cm^2])$^{1.5}$ and FN BMAD was calculated with the formula FN BMAD[g/cm^3] = (BMC [g]/area [cm^2]).

As no reference curves for DXA results are available for Caucasian or Asian girls aged 15 to 17 years, we used the UK reference data for DXA in children aged 6 to 17 years for LS comparison of BMA,[18] and US girls aged 15 to 18 years for FN comparison.[19]

Pubertal Stage

A female nurse, who measured weight and height, also assessed the Tanner stages for breast, pubic, and armpit hair development by showing standard drawings to the girls (we could not perform a clinical breast and pubic hair inspection for ethical reasons). Questions regarding menarche and the menstrual cycle were asked in conjunction with questions on dance training by way of a questionnaire that was filled out with the dancer in a personal interview, in the presence of a professional interpreter when necessary. The questions were: Do you menstruate? If so, when did it start? Do you have menstrual irregularities? If yes, what are they? Do you use the birth control pill? The questions concerning dancing were: At what age did you start dancing? How many hours per week did you dance in the last six months?

Statistical Analysis

Analyses were performed with SPSS version 15.0 (SPSS Inc, Chicago, IL, USA), as well as STATA 10.0 (College Station, Texas, USA). Descriptive statistics (mean and standard deviation) were determined for all variables by using SPSS; STATA was then used for the remaining analyses. Data were checked for normality with the Kolmogorov-Smirnov test. Because variables were not normally distributed except for age, weight, height, and BMI, non-parametric tests were performed. In order not to overlook eventual differences between Caucasians and Asians, the two groups were compared by Mann-Whitney tests. Because differences were found, Spearman correlations were used between bone measurements and other parameters for Asians and Caucasians separately. Bivariate and multivariate analyses by robust regression of the LS-BMC and FN-BMC adjusted for height by including the covariate height in each regression model were also undertaken.

Results

All Subjects (N = 127)

Tables 1, 2, and 3 summarize the participants' general characteristics, pubertal development, dancing habits, nutritional data, and bone density. BMI was evaluated with respect to age of each dancer in accordance with Cole and associates.[11] Only 42.5 % (N = 54) had a normal BMI for age, while 41.7% (N = 53) had Grade 1 thinness (37.3 % of the Caucasian dancers, N = 25, and 46.7% of the Asian dancers, N = 28). Grade 2 thinness was found in 12.6% of dancers (7.5% of the Caucasian, N = 5, and 18.3% of the Asian dancers, N = 11), and Grade 3 thinness was found in 6.7% (N = 4), all in the Asian group. Of the total population 10 participants had primary amenorrhea, and one had secondary amenorrhea. None reported taking either birth control pills or nutritional caloric supplements. Fifty-seven percent (N = 72) took multi-mineral supplements, vitamins, or both; 13% (N = 16) took only calcium supplements. There were no differences between Asians and Caucasians in this respect.

Mean LS BMAD of the whole group (0.126 g/cm^3) was 37% below the fifth percentile (0.200 g/cm^3),

Table 1 General Characteristics, Pubertal Development, Dance Habits, Nutritional Data, and Bone Density in 127 Adolescent Dancers, Means and Standard Deviations

	All subjects N = 127	Caucasian N = 67	Asian N = 60
General Characteristics			
Age (y)	16.7 (0.8)	16.6 (0.8)	16.7 (0.8)
Weight (kg)	47.8 (4.9)	49.4 (4.7)	46.0 (4.5)*
Height (cm)	163.6 (6.1)	164.8 (6.1)	162.3 (5.9)*
BMI (kg/m2)	17.8 (1.3)	18.2 (1.2)	17.5 (1.2)*
Pubertal Development			
Age at menarche (yrs)	13.9 (1.3) N = 117	14.1 (1.2) N = 60	13.8 (1.3) N = 57
Years since menarche	2.6 (1.5)	2.6 (1.3) N = 60	3.0 (1.5) N = 57
Primary amenorrhea	N = 10	N = 7	N = 3
Breast development (Tanner score)	2.9 (0.7)	3.1 (0.81)	2.63 (0.56)*
Pubic hair development (Tanner score)	3.4 (0.6)	3.64 (0.59)	3.23 (0.58)*
Dancing			
Hours of dancing/week	22.1 (7.6)	24.1 (7.7)	19.8 (6.9)*
Age at onset of dancing (years)	5.8 (1.9)	5.41 (1.66)	6.19 (2.14)
EAT 40 (score)	12.6 (7.9)	10.2 (7.5)	15.3 (7.6)*
Dietary Record (portions†)			
Nondairy proteins (portions)	2.2 (1.2)		
Recommended number of portions	1	1.8 (1)	2.7 (1.3)*
Dairy products (portions)	1.8 (1)		
Recommended number of portions	3-4	1.9 (0.9)	1.7 (1)
Fruits and vegetables (portions)	4 (1.6)		
Recommended number of portions	5	4 (1.5)	3.9 (1.7)
Starchy food (portions)	3.1 (1.1)		
Recommended number of portions	minimum 3	2.9 (1.1)	3.3 (0.9)*
Bone Measurements			
LS-BMC (g)	52.50 (8.7)	52.17 (8.23)	52.81 (9.15)
LS-BMAD (g/cm^3)	0.126 (0.011)	0.125 (0.011)	0.126 (0.011)
FN-BMC (g)	4.30 (0.5)	4.33 (0.536)	4.19 (0.503)
FN-BMAD (g/cm^3)	0.209 (0.030)	0.207 (0.031)	0.211 (0.03

*Significant difference between Caucasians and Asians with Mann-Whitney test ($p < 0.05$). †Portions according to definitions of the Swiss Society of Nutrition.[9] BMC = bone mineral content; BMAD = bone mineral apparent content; BMD = bone mineral density; FN = femoral neck; LS = lumbar spine.

Table 2 BMI Compared to Age-Specific Normal Values

Age (years)	Number	Average BMI (kg/m2)	Average BMI Caucasians (kg/m2)	Average BMI Asians (kg/m2)	Lower normal BMI limit for age & sex (kg/m2)[11]
15.0 - 15.4	9	17.1	17.4	16.9	17.45
15.5 - 15.9	18	17.7	17.9	17.4	17.69
16.0 - 16.4	23	17.7	18.0	17.1	17.91
16.5 - 16.9	28	18.0	18.2	17.8	18.90
17.0 - 17.4	25	18.6	18.8	18.1	18.25
17.5 - 18.0	24	17.5	17.9	17.1	18.38

and mean FN BMAD (0.209 g/cm^3) was significantly higher ($p < 0.01$) than the mean value of the reference population (0.188 g/cm^3).[18] We found no reference curves for BMC, or ethnicity-specific reference data.

Qualitative food intake assessed by DR showed that the average intake of starchy food was as recommended, fruits and vegetables were slightly below recommended levels (four portions instead of five), and consumption of dairy products was very low (1.8 portions instead of the 3 to 4 recommended), but that non-dairy proteins (meat, fish, and eggs) were consumed at more than twice the dietary recommendation of one portion. The Mann-Whitney tests showed that, compared to Caucasians, Asians were significantly smaller, weighed less, had a lower BMI, a higher (and abnormal) EAT 40 score, a lower breast and pubic hair development Tanner score, fewer hours of dancing per week, and clear differences in food intake. In Asians,

Table 3 BMI by Age (Caucasians/Asians)*

Age (years)	Normal	Grade 1 thinness	Grade 2 thinness	Grade 3 thinness
15.0 – 15.4	2/1	2/3	0/1	0/0
15.5 – 15.9	7/5	3/0	0/2	0/1
16.0 – 16.4	7/1	5/6	2/2	0/0
16.5 – 16.9	8/5	3/9	2/0	0/1
17.0 – 17.4	10/4	4/6	0/0	0/1
17.5 – 18.0	3/1	8/4	1/6	0/1
Total	37/17	25/28	5/11	0/1
%	55%/28.3%	37.5%/46.7%	7.5%/18.3%	0%/6.7%

*International cut-off points for BMI (thinness) by sex by age, based on pooled international data for BMI and linked to the World Health Organization's recommended adult cut off points BMI of 16 (Grade 3), 17 (Grade 2), and 18.5 (Grade 1) at age 18, obtained by averaging data from Brazil, Great Britain, Hong Kong, Netherlands, Singapore, and USA.[11]

the intake of meat, fish, and eggs was 50% higher than in Caucasians (2.7 versus 1.8 portions; $p < 0.05$), and starchy food was 14% higher (3.3 versus 2.9 portions, $p < 0.05$). Because of these differences, results had to be reported separately for these ethnic sub-groups.

Correlations

Analysis of the BMC data of the whole group showed several significant correlations (Spearman) with regard to anthropometric, dietary, and pubertal parameters (Table 4). We also performed robust regression analysis adjusted to height in order to examine bivariate associations between BMC and the independent variables. Significant bivariate predictors were included in a multivariate robust regression model.

1. Lumbar spine BMC: The following variables were positively associated with LS-BMC: age, weight, height, BMI, years since menarche, and dairy intake. Three variables remained significant in this model: age, height, and dairy intake.

2. Femoral neck BMC: The following variables were significantly and positively associated with FN-BMC: weight, height, BMI, hours of dancing per week, and dairy intake, while the intake of non-dairy proteins (meat, fish, and eggs) was negatively correlated. Three variables remained significant in this model: weight, non-dairy proteins, and dairy intake (Table 4).

3. Lumbar spine BMAD: Analysis of the BMAD data of the total group produced the following results: age and years since menarche were significantly and positively associated with LS-BMAD, while the intake of non-dairy proteins was negatively associated. These three variables remained significant in this model.

4. Femoral neck BMAD: For FN-BMAD, the following variables were significantly and positively associated: weight, BMI, age at onset of dancing, and dairy intake. Two variables remained significant in this model: BMI and dairy intake (Table 5).

We found no significant diffe-

Table 4 Bivariate and Multivariate Analysis by Robust Regression of the BMC Lumbar Spine and BMC Femoral Neck, Adjusted for Height (N = 127)

	Bivariate Analysis		Multivariate Analysis	
BMC Lumbar Spine	Coeff	P-value	Coeff	P-value
Age (y)	2.40	0.009	2.22	0.012
Weight (kg)	0.48	0.021		
Height (cm)	0.39	0.001	0.38	0.015
BMI (kg/m2)	1.28	0.020		
Years since menarche	1.10	0.016		
Dairy intake (portions)	1.84	0.008	1.69	0.015
	Bivariate Analysis		Multivariate Analysis	
BMC Femoral Neck	Coeff	P-value	Coeff	P-value
Weight (kg)	0.063	< 0.001	0.058	< 0.001
Height (cm)	0.036	< 0.001		
BMI (kg/m2)	0.165	< 0.001		
Hours of dancing per week	0.012	0.028		
Non-dairy proteins (portions)	-0.089	0.008	-0.62	0.045
Dairy products (portions)	0.083	0.049	0.069	0.067

No significant association: ethnicity, age at menarche, primary amenorrhea, EAT 40 Score, Tanner score (breast and pubic hair), age at onset of dancing, fruit and vegetable intake, starchy intake.

Table 5 Bivariate and Multivariate Analysis by Robust Regression of the BMAD Lumbar Spine and BMAD Femoral Neck (N = 127)

	Bivariate Analysis		Multivariate Analysis	
BMAD Lumbar Spine (LS)	Coeff	P-value	Coeff	P-value
Age (y)	0.004	0.001	0.003	0.014
Years since menarche	0.002	0.001	0.002	0.036
Meat-fish-egg intake (portions)	-0.002	0.008	-0.002	0.006
	Bivariate Analysis		Multivariate Analysis	
BMAD Femoral Neck (FN)	Coeff	P-value	Coeff	P-value
Weight (kg)	0.0012	0.032		
BMI (kg/m2)	0.007	0.002	0.007	0.001
Age at onset of dancing	0.004	0.004	0.004	0.001
Dairy intake (portions)	0.005	0.071 (trend)		

No significant association: ethnicity, height, age at menarche, primary amenorrhea, EAT 40 Score, Tanner score (breast and pubic hair), hours of dancing per week, fruit and vegetable intake, starchy intake.

rences between the girls with primary amenorrhea, those with secondary amenorrhea, and those with normal menstruation with regard to the parameters measured in this study. For this reason, we did not undertake any subgroup analysis according to menstruation. Girls with primary amenorrhea naturally were not included in the parameter "years since menarche."

Analysis by Ethnic Origin

Because there were differences between the ethnicities, sub-group analysis was undertaken for the two ethnic groups. In these subgroups, no significant correlations were found between BMC (height adjusted) and any of the measured parameters, except for a negative correlation between FN-BMC and fruit and vegetable intake (< 0.05). For BMAD, several correlations were found with anthropometric, dietary, and pubertal parameters (Table 6). In Caucasians, LS-BMAD correlated positively with age, years since menarche, and dairy intake ($p < 0.05$), while FN- BMAD correlated negatively with meat-fish-egg intake ($p < 0.05$). In Asians, LS-BMAD correlated negatively with dairy intake ($p < 0.05$), while FN-BMAD correlated positively with weight and BMI, and negatively with non-dairy protein intake ($p < 0.05$).

Discussion

Before discussing the influence of dancing, menstrual stage, and food consumption on bone health in this cross-sectional study, it should be noted that in this population the average Body Mass Index was below or near the lower normal limit for age and sex. Since quantitative energy intake could not be assessed, low body weight in relation to height and age was taken as a surrogate measure for the appropriateness of each subject's total energy intake. The low average BMI for age (grade 2 and grade 3 thinness in approximately 15% of study participants) of this adolescent population with intense exercise allows for the assumption that the total energy intake was low in about 15% of the dancers. In addition, the assessment of food intake with DRs in ballet dancers has to be viewed with caution in light of evidence of major under-reporting.[20]

The differences between Asian and Caucasian dancers, which led us to undertake subgroup analysis, also deserve some introductory comments. The observed differences in pubertal

Table 6 Significant Spearman Correlation Coefficients ($p < 0.05$) Between BMAD and Anthropometric, Dietary, and Pubertal Parameters in Caucasian and Asian Adolescent Dancers

	Caucasians (N = 67)		Asians (N = 60)	
	BMAD LS (gcm3)	BMAD FN (g/cm3)	BMAD LS (g/cm3)	BMAD FN (g/cm3)
Age (yrs)	0.369†	—	—	—
Weight (kg)	—	—	—	0.417†
BMI (kg/cm^2)	—	—	—	0.544†
Years since menarche	0.304*	—	—	
Meat, fish, egg intake (portions) a	-0.303*	—	—	-0.301*
Dairy products intake (portions) b	0.323†	0.249*	-0.305*	—

*p < 0.05 †p < 0.01. Non-significant: Age at menarche, age at onset of dancing, breast development and pubic hair development (Tanner Score), fruit and vegetable intake, starchy food intake, Score EAT 40. LS = lumbar spine, FN = femoral neck.

stages according to Tanner criteria are most probably conditioned by racial factors, since Asians and Caucasians had their menarche at the same age. Concerning the nutritional aspect, Asians showed a 50% higher intake of meat, fish, and eggs and a 14% higher intake of starchy food, which can be explained by the habit, reported by some Asian participants, of consuming these food products at each meal, starting with breakfast. The lower BMI observed in Asians is probably explained by lower energy intake and ethnic differences; indeed, their EAT 40 scores, which indicate the probability of eating disorders,[21] are 50% higher than those of the Caucasian dancers. This raises the question of whether they are exposed to more restrictive recommendations from their teachers compared to the Caucasians (the difference cannot be explained by higher energy expenditure, as they dance fewer hours per week).

Nutritional Aspects

Five percent of Asian dancers and 2.5% of Caucasians showed a high risk of anorexia, with EAT 40 scores greater than 30. Ballet dancers often practice unhealthy behaviors like food restriction, fasting, excessive exercise, binge eating, vomiting, and use of laxatives.[22] The pressure for maintaining a very thin body makes young ballet dancers particularly vulnerable to the development of eating disorders.[23] The reported incidence of eating disorders among ballet dancers varies between studies. Up to 7.6% may have anorexia, compared to 0.1% to 1% in the general population.[23] The low average body weight observed in our study might be partially associated with nutritional deficiencies; indeed, the majority of food groups were consumed below the recommended frequency. Only the non-dairy proteins were consumed 2.2 times more frequently than recommended. This suggests that the total protein intake was high with regard to calcium intake, whereas a small previous study showed a low protein intake in 20 Caucasian ballet dancers aged 16 to 29 years.[1]

Dairy products, the major source of nutritional calcium, were consumed in the present study at the rate of 1.8 portions per day on average, instead of the 3 to 4 portion RDA, and only 13% of the dancers took calcium supplements. Therefore, calcium needs were probably not met. Some calcium supplementation studies, but not all, have shown that calcium intakes higher than 1,000 mg per day increase bone mass in adolescent females, and calcium supplementation has been found to enhance bone mineral density in adolescent girls.[24,25] In addition, in the presence of insufficient calcium intake, protein does not confer as much benefit to bone mineral mass.[26] The importance of calcium from dairy sources was demonstrated in our study by its positive correlation with LS-BMC and FN-BMC in the bivariate and multivariate analysis, and with LS-BMAD and FN-BMAD in Caucasians. Surprisingly, it correlated negatively with LS-BMAD in Asians. This could be linked to very frequent lactose intolerance in Asians,[27] which might have interfered negatively with mineral absorption, especially in those with the highest dairy intake.

Concerning the non-dairy protein intake, it correlated negatively with FN-BMC and LS-BMAD in the bivariate and multivariate analysis. In the subgroup analysis, there was again a negative correlation with LS-BMAD in Caucasians and with FN-BMAD in Asians. A high protein intake is not in itself detrimental to bone, but such a relatively high intake of non-dairy proteins can be a marker for "displacement" –a low intake of other nutrients, such as dairy products, leading to a disturbed balance between the relatively high intake of non-dairy proteins (more than twice the recommended number of portions in Asians) and a relatively low intake of calcium. A negative impact of this type of intake has been demonstrated in adults. [28] A moderate but significant negative relationship between protein intake and total BMD has also been shown by Yannakoulia and associates[29] in 31 pre-professional ballet dancers.

Although we could not measure the acid load of the diet, acid-base theory might be another hypothetical explanation for a negative impact, because a high nutritional acid load is detrimental to bone health. In our subjects, an eventual negative influence of the relatively high intake of acidifying non-dairy proteins would be exacerbated by an insufficient alkaline intake from fruits and vegetables.

These results show that the intake of dairy products is a positive determinant for the development of bone, while an excessive intake of non-dairy proteins seems to be negative. They illustrate the importance of a balanced diet in ballet dancers. Indeed, adequate nutrition is now a priority in the majority of ballet schools, and recently nutrition intervention programs have been tested on ballet dancers,[22] but there are still inappropriate eating behaviors and inaccurate beliefs among this population.

Aspects of Pubertal Development

Intense physical activity together with the pursuit of thinness also affects young dancers' menarche. Numerous studies have shown menstrual dysfunction in female athletes and ballet dancers. In our study, menarche occurred at 14.1 years in Caucasians and 13.8 years in Asians. This represents a delay of 17 months compared to data from NHANES (the National Health and Nutrition Examination Survey, a series of studies designed to assess the health and nutritional status of adults and children in the United States).[30] A recent study also showed some delay of menarche in non-professional dancers compared to controls, although growth patterns were similar.[20] However, the intensity of dancing was much lower (5.5 hours per week compared to 22.1 hours per week) than in our study. Exercise alone is not known to lead to menstrual disturbances, and low body weight in itself is not a cause of delayed puberty. On the other hand, low energy intake has been shown to interrupt LH pulsatility in normal young women.[31] It has even been suggested that treatment of functional menstrual disorders should aim at dietary reform. This can be applied here, although psychological stress may also play a role. In any case, the number of years during which these girls were exposed to estrogen is crucial for their bone maturation. For this reason, it is understandable that the more years passed since menarche and the later in age dancing was started, the better the bone measurements would be at the LS (significant in Caucasians, trend at $p < 0.1$ in Asians). This does not apply to the FN, because it is more influenced by the mechanical stimulation of dancing.

Aspects of Physical Activity

Physical activity is an important contributor to bone strength, especially in adolescence, and the increasing levels of physical activity during childhood are likely to enhance optimal bone strength, leading to high peak bone mass.[21,32] This beneficial effect can be lost if nutritional energy intake does not match caloric needs, which can lead to menstrual disturbances, low estrogen, and resultant low bone mass.[31,33] The effort required for dancing corresponds to a moderate-intensity physical activity,[34] but because of the impressive number of hours these girls dance per week (22.1 hours on average), their energy expenditure adds up to 5,100 cal/week, which corresponds to that of a high-intensity activity.[34] Nonetheless, it can be assumed that dancing has a positive effect on bone as a result of the repeated mechanical impact. Indeed, in the present study the mean apparent bone density of the femoral neck was above the mean reference value, while that at the lumbar spine it was below. In addition, we found a significant positive association between the hours of dancing per week and FN-BMC. It has already been shown that the BMD of retired dancers is the same as in controls when measured at weightbearing sites, but significantly lower at non-weightbearing sites.[35] Another study has reported that the femoral neck in dancers with a history of amenorrhea is protected by virtue of being the major weightbearing site[36] but that the BMDs of LS and FN were lower in amenorrheic compared to eumenorrheic dancers. This demonstrates the influence of both physical activity and hormonal status. The subjects in the present study had low bone parameters despite mechanical stimulation, perhaps as a consequence of delayed puberty associated with intensive physical activity and low nutritional intake (low body weight).

Study Limitations

This study has several limitations and biases. The number of subjects is relatively large compared to other studies of ballet dancers but still small in absolute values. This is a cross-sectional study that examines associations between various factors, and therefore it cannot prove causal interrelationships.

For cultural and ethical reasons, the data on Tanner stages of development were collected through self-report during interviews with the female nurse. The physical examination was perform with the subjects in dance leotards. Therefore, the results may be less accurate than if recorded by direct observation.

We used qualitative dietary records (DRs) because, due to different multi-cultural dietary habits, it was impossible to make a precise quantitative assessment of food consumed. There are possible errors associated with the use of DRs, such as under-reporting or changes in food habits during the recording period. The cultural differences might have induced a misunderstanding of certain questions and documents. We wanted to also use a Food Frequency Questionnaire (FFQ) but realized how difficult it would be to develop an understandable multilingual FFQ for so many different nationalities with such a large variety of food habits. FFQs should be used in homogeneous populations, which was not the case here. Therefore, we ultimately chose to use only DRs.

There is a lack of reference curves for DXA results in Caucasian and Asian girls 15 to 17 years of age. This is why we used the UK reference data for DXA in children aged 6 to 17 years for comparison of BMAD. However, these references are for Caucasians only. As an alternative, in future studies the use of a control group could be of interest.

There are racial differences in anatomic segment proportions, as Caucasians tend to have longer legs than Asians but similar trunk length.[37] Adjustment for segment length instead of total height would have yielded more appropriate measurements but was not possible with our data.

Conclusions

Our findings confirm that BMI and the number of years since menarche are positively correlated with BMC and BMAD. They also show that the number of food portions consumed by dancers is below RDAs, except for non-dairy proteins. Bivariate and multivariate analysis confirmed the positive influence of dairy intake and the negative influence of non-dairy protein intake on BMC.

Recommendations

These findings allow for the formulation of some recommendations. Appropriate weight gain has to be obtained during growth, with maintenance of a BMI above a Z score of -2 (-2 SD); that is, not beneath 16kg/m^2 at age 15, 16.4 kg/m^2 at age 16, 16.8 kg/m^2 at age 17, and 17 kg/m^2 at age 18. With proper controls pubertal delays should be detected early, at least by the age of 16 years. Eating disorders have to be suspected when weight and height deviate from the normal growth chart curves. A balanced diet is to be recommended: dairy products should be consumed in sufficient quantities (3 to 4 portions a day, at least in Caucasians) to cover calcium needs. Excess intake of non-dairy proteins of more than one portion per day should probably be avoided, especially if they are consumed in place of other important food groups like dairy products and fruits and vegetables, which in this study were consumed in low quantities. These measures might be useful in preventing delays in the development of body size and weight, and of bone strength.

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