Effects of 3 years of ballet training on bone health, body composition, and physical performance in elite adolescent dancers

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Summary

Objectives. We aimed to assess the impact of ballet training on multiple parameters of musculoskeletal development in a group of elite adolescent dancers with respect to body and bone composition, mobility and strength, and physical performance over a period of three years.

Design. Subgroup analysis of a prospective cohort study consisting of elite adolescent ballet dancers of the Royal ballet school of Antwerp, who had longitudinal follow-up data available during their first and third year of training.

Methods. Baseline and follow-up data were available for 10 dancers (mean age at baseline 12.40 ± 0.38) out of 38 participants in the cohort study. The total body (TB) and upper and lower limb regions bone mineral density (BMD) and bone mineral content (BMC) were assessed using dual X-ray absorptiometry. Physical performance were also assessed.

Results. Compared to baseline in the first year of training, lean mass, BMD total and BMD legs improved significantly over time (P<0.005). There was also a significant correlation between Δ-BMC left and Δ-power both plantar flexors (ρ=0.721; P=0.019) and Δ-BMC left and Δ-isometric both plantar flex (ρ=0.685; P=0.029).

Discussion. The causal association of changes in musculoskeletal development with ballet training cannot be ascertained because of the lack of a control group and the small size. Insights into the relationships between site-specific bone density and foot strength may guide future studies for a better understanding of the impact of dance training on bone and muscle development.

KEY WORDS: bone accrual; physical performance; weight bearing exercise; fracture risk; elite adolescence dancers; ballet training.

Introduction

Literature about musculoskeletal development in dancers is contradictory since many factors can interact with dance training, including hormonal status, nutrition, pharmacological treatments, individual variability to mechanical load, physical activity habits prior to dancing and local load variation (1, 2). On the other hand, in a recent cross-sectional study, repetitive short stretching cycle (SSC) of ballet jumps has been associated with improved bone mineral density, bone mineral content and bone strength indices (3). An important area of research focuses on weight-bearing activities as a modifiable determinant of peak bone mineral accrual (4). Classical ballet is a model of weight-bearing activities based on specific jumps and landings which are able to promote an osteogenic stimulus with unusual and high-impact loads on the skeleton (5). Adolescent elite dancers are potentially at risk to develop the female athlete triad (menstrual dysfunction, disordered eating and decreased bone mineral density), also known as relative energy deficiency in sports (RED-S) (6). Performance stress as well as aesthetic needs could lead to excessive leanness and over control of body weight with a negative impact on bone development (7). An observational study based on a group of dancers involved in a regular intensive weight-bearing exercises, showed a higher bone mineral density (BMD) in the axial and appendicular skeleton than controls, but this advantage was lost when they developed oligo/amenorrhea (8). Based on the current literature, the conflicting results may also be due to differences in dancers’ performance levels, study design and methodologies employed (9). Information about frequency, intensity, time, timing and type of dance training and their influence on peak bone mass are still lacking. Moreover, structural and functional asymmetry in dancers could play a role in contributing to injury and the existence of laterally biased dance experience needs further investigations (10). There is a need to quantify the dance weight-bearing movements which are osteogenic and to better define, with longitudinal studies, the effects on musculoskeletal development, throughout professional training. Our study is aimed to assess the improvements on body and bone mass parameters, in a population of dancers involved in a specific dance program over three years. In the same group, we also assessed mobility, strength and physical performance across the time.
Methods

The Royal Ballet School of Antwerp, Belgium is a ballet dance school designed to prepare students aged 12 to 18 for a professional dancing career. This study reports on a subgroup of dancers from a cross-sectional study that was performed from 2011 to 2013 and 2016 to 2017, who had both baseline (first year) and follow-up (third year) data available. Across these three years of practice, ballet training was based on 5 hours per day of training and a total of 23 hours per week (18 hours of classical ballet, 3 hours of contemporary and 2 hours of modern) (Tables 2, 3). The ethics advisory board of the Antwerp University Hospital approved the study (12/49/394). Signed assent forms were obtained from all participants and signed consent forms from their parents or legal guardian. Assessments included: body composition (BMI, DXA), bone density (DXA), a-ROM lumbar spine (3d motion analyser), lower limb strength (work simulator dynamometer), physical performance (Sit and reach, Beighton score, Flamingo balance test, Plank test). No information on diet was collected. For body composition and bone mineral density assessment a Dual-energy X-ray absorptiometry (DXA) was used (GE Lunar Prodigy densitometer, General Electric, Madison, Wisconsin USA). All data were analyzed using software version 13.40. Measurements were performed by one specially-licensed and certified nuclear medicine technician. Tissue fat percentage and region fat percentage were calculated. Bone mineral density in grams per unit projected area (g/cm²) was measured at the spine, legs and arms. For the site specific analysis, we considered the bone densitometry at the legs arms, spine and pelvis, but not at the hips because it is considered a preferred measurement site in growing children, due to variability in skeletal development (11). Measurement of lumbar spinal motion was performed using a 3D motion analysis system (Zebris® CMS 70P, CA 6000 Spine Motion Analysis, Germany) able to record the angular changes of joint in motion by using high frequency sound waves (12). The markers were placed on the skin sending intermittent high frequency ultrasonic sound waves. The receiver microphones captured the sound waves produced by the markers and then a unit integrates the markers, sensors, adapters and computer in order to convert the sound waves into data. Dancers were examined in sitting position with the arm crossed for all the range of motion of lumbar spine (flexion, extension, rotation and lateral bending, both sides). Since biomechanics of the foot plays a central role in classical ballet technique and the structure of ankle and foot are common site of injury (13), we aimed to assess ankle strength improvement over the time. We used the PrimusRS isokinetic dynamometer machine (BTE technologies Inc., Hanover, MD, USA) (14). Subjects was seated in an upright position (with an angle of 80° between upper body and thighs). The upper body, waist and thighs were stabilized using specific straps to control for extraneous body movements. The test aimed to assess isometric strength (Nm), power (W) and endurance (J) of the right and left ankle plantar flexors. The sit-and-reach test (SART) is one of the most common test to evaluate flexibility and previous studies have reported a very high intra and inter-rater reliability for the sit and reach test (15). Participants assumed the long sitting position barefoot and placed their soles against the sit and reach test box at the 26 cm mark. Then, they were asked to place one hand on top of the other and slowly flex their trunk forward trying to reach the most distant point with their fingertips while keeping their knee extended. Three measurements were recorded and the best two were averaged and used for the analysis. Since some studies reported a high prevalence of joint hypermobility syndrome in dancers and a correlation between hypermobility and injury (16, 17), we also included the Beighton score assessment. The Beighton score aimed to quantify joint laxity and hypermobility by using a 9-point system. Previous studies used the plank test and the Flamingo balance test for the assessment of the physical performance of core musculature (18). Lower flamingo balance scores indicate a better whole body balance. Whole body balance (flamingo balance) was assessed as the number of trials needed to maintain the balance on their preferred foot on a flat firm surface. While balancing on the preferred foot (shoes removed), the free leg is flexed at the knee and the foot of this leg held close to the buttocks. Trunk endurance was estimated by the plank test: the prone bridge position was maintained supported by the forearms and feet in contact with the ground. Elbows were placed at 90° of flexion underneath the shoulders, while the neck and hip were maintained in neutral position. The time resting stable in this position was measured.

All analyses were performed using SPSS (version 21). Outlying, unusual or missing entries were checked with the original questionnaires and corrected where necessary. Results are reported as the mean ± standard deviation (SD) or range. The change between baseline and follow-up of measured variables was examined using the Wilcoxon signed rank test. The Spearman method was used to identify correlations between changes of measured variables from baseline to follow-up. The level of significance was set at P<0.05.

Results

A total of 10 dancers (5 males and 5 females; mean age at baseline 12.40 ± 0.38 years) had baseline and follow-up data available and were included in this analysis. The mean age for starting dance training was 6 years, while the mean age for starting the pointe training was 11 years.

Anthropometric measures, body composition and Bone mineral density

Baseline and follow-up anthropometric measures are shown in Table 1 and BMD results are summarized in Table 2. As it could be expected because of growing (19, 20), there were statistically significant improvements over time in weight (kg), height (cm), BMI (kg/cm²), BMD total (g/cm²), BMC (g), BMD legs and BMD arms (g/cm²) and lean mass (kg). While Z-score remained comparable between baseline and follow-up measurements, there was a small increase in Z-score TBLH (P=0.033).

Low back flexibility

Flexibility improved significantly after three years of practice in back flexion (P<0.025), but not in extension (P=0.960) or in the back rotation to both sides (P=0.202 at right side, P=0.575 at left side). A small degree of asymmetry was found in the frontal plane of movement: lateral flexion to the left side improved in a statistically significant way (P=0.037) but not to the right side (P=0.153) (Table 3).
Table 1 - Anthropometric measures.

<table>
<thead>
<tr>
<th>Anthropometric values</th>
<th>Baseline Mean±SD</th>
<th>Follow-up Mean±SD</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>12.4±0.4</td>
<td>14.8±0.3</td>
<td>0.005*</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>35.8±5.9</td>
<td>49±7</td>
<td>0.005*</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>151.1±9.6</td>
<td>166±8</td>
<td>0.005*</td>
</tr>
<tr>
<td>BMI (kg/cm²)</td>
<td>15.1±1.9</td>
<td>17.7±1.3</td>
<td>0.005*</td>
</tr>
</tbody>
</table>

Table 2 - Bone mass parameters.

<table>
<thead>
<tr>
<th>Bone density</th>
<th>Baseline Mean±SD</th>
<th>Follow-up Mean±SD</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMD total (g/cm²)</td>
<td>0.92±0.03</td>
<td>1.03±0.05</td>
<td>0.005*</td>
</tr>
<tr>
<td>BMC (g)</td>
<td>1464.6±183.3</td>
<td>2080.6±297.0</td>
<td>0.005*</td>
</tr>
<tr>
<td>BMD legs (g/cm²)</td>
<td>0.95±0.04</td>
<td>1.1±0.7</td>
<td>0.005*</td>
</tr>
<tr>
<td>BMD arms (g/cm²)</td>
<td>0.709±0.111</td>
<td>0.739±0.019</td>
<td>0.386</td>
</tr>
<tr>
<td>Z-score</td>
<td>-0.51±0.46</td>
<td>-0.49±0.29</td>
<td>0.720</td>
</tr>
<tr>
<td>Z-score TBLH</td>
<td>-0.51±0.29</td>
<td>-0.20±0.32</td>
<td>0.033*</td>
</tr>
<tr>
<td>Lean mass (g)</td>
<td>30579±5035</td>
<td>42127±7280</td>
<td>0.005*</td>
</tr>
<tr>
<td>Fat mass (g)</td>
<td>4436.7±1088.8</td>
<td>5423.1±1381.5</td>
<td>0.139</td>
</tr>
</tbody>
</table>

Table 3 - Lumbar Range of motion.

<table>
<thead>
<tr>
<th>ROM (°)</th>
<th>Baseline Mean±SD</th>
<th>Follow-up Mean±SD</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>76.9±12.0</td>
<td>66.1±12.1</td>
<td>0.025*</td>
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<tr>
<td>Extension</td>
<td>-43.4±10.3</td>
<td>-46.6±11.4</td>
<td>0.575</td>
</tr>
<tr>
<td>Rotation R</td>
<td>24.3±6.3</td>
<td>21.5±4.1</td>
<td>0.202</td>
</tr>
<tr>
<td>Rotation L</td>
<td>-22.8±5.6</td>
<td>-21.8±4.6</td>
<td>0.575</td>
</tr>
<tr>
<td>Lateral flexion R</td>
<td>39.6±6.2</td>
<td>34.0±8.2</td>
<td>0.153</td>
</tr>
<tr>
<td>Lateral flexion L</td>
<td>-39.2±6.1</td>
<td>-32.9±8.0</td>
<td>0.037*</td>
</tr>
</tbody>
</table>
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**Ankle plantar flexors strength**
Significant improvements were observed for isometric ankle plantar flexors (Nm) both sides (left: P=0.028; right: P=0.13), power ankle plantar flexors (W) (P=0.009), torque in concentric and eccentric phase (Nm) at left side (P<0.028), and at right side (P=0.013).

**Figure 1** - Δ-BMC left and Δ-isometric both plantar flex (Nm) correlation.

Significant correlations were identified between: the Δ-BMD legs and Δ-power right plantar flex (W) (ρ=0.648; P=0.043), the Δ-BMC left and Δ-power both plantar flexors (W) (ρ=0.721; P=0.019; Figure 1) and the Δ-BMC left and Δ-isometric both plantar flex (Nm) (ρ=0.685; P=0.029) (Figure 2).

**Physical performance**
Compared with baseline, there was significant increase in flexibility as measured by the sit-and-reach test, and endurance assessed using the plank test (P=0.005), but not according to the Flamingo balance and Beighton scores.

**Conclusion**
According with growth, lean mass significantly improved while fat mass did not increase, probably due to the dance exercise. Bone mineral density (BMD total), bone mineral content (BMC) and BMD legs improved over the time, while BMD arms did not improve over the time. This could be due to the site-specific effect of training at impact-sites, as previous studies already reported in professional dancers (21). Flamingo balance and Beighton score were not modified after three years showing that dancers were already good in balance and joints flexibility before being enrolled in the Royal Ballet School. Zebris spine-analysis revealed no significant modifications in lumbar spine mobility except for the lumbar flexion and lateral left bending. These results are in accordance with previous studies which showed that as the age and body weight increase, lumbar spine ROM decreases (22). The lateral bending at left side, but not at right side, significantly improved over the time. Even if our results are ambiguous, we should suppose a certain degree of asymmetry during dancing training. This could be due to the lateral preference in dancers as an effect of some specific exercises as pirouettes, in which feet produce rotation of the body for turns or as barre exercises, based on back flexion, extension and lateral bending; during these movements, dancers and teachers often pay more time and attention at right side than left side (23). As an effect of ballet training program, sit-and-reach test showed a significant improvement on hamstring (biceps femoris, semimembranosus and semitendinosus) flexibility. These muscles play a central role in ballet technique as their inadequate flexibility does not allow adequate forward rotation of the pelvis, which is required for the aesthetic needs, a proper spine alignment and a correct execution of movements (24, 25). Due to the strengthening of core muscle with training, we also observed an improvement in core endurance after three years of practice, as assessed by plank test. Foot muscle strength in term of isometric, power and endurance, improved significantly over three years as an effect of weight-bearing dance movements which is specifically targeted on ankle plantar flexors muscles. There was also a positive correlation between foot plantar flexor strength improvements and legs BMD improvements. This could support the hypothesis that the typical ballet jumping and landing, based on foot plantar flexors activation, could have an effect on site specific bone density. We did not measure the correlations between site-specific BMD density (difference T1-T0) and muscle strength (difference T1-T0) in other body regions. On the other hand, data showed that BMD arms did not improve in these dancers population across the time. The present study might have been influenced by methodological limitations since the skeletal maturation wasn’t measured by Tanner Stage, neither by X-ray at the hand-wrist bones. We also acknowledge the lack of injury and fracture records for our participants. We considered the clinical relevance and menstrual age, but we did not assess the peak bone height (PBH) and the peak height velocity (PHV). No information was available concerning nutrition from our population. We cannot compare our results with normal values since there was no untrained control group. The small size of our population represents a limitation, although the low number of participants resulted from the need to control the dancers’ workload and the performance. The best way to achieve this objective was to assess a group of dancers starting the
same dancing program, supervised by the same teacher. The fact that the age of the patients was low, is a strength of our study, as it allowed us to assess the changes across puberty. Ballet training combined with other factors, could have an influence on bone health. The improvements over the time in term of bone mass and performance are related both to growth and training but Z-score values are not as high as we expected for these trained populations, even before starting training. Nevertheless, dancer teachers should be aware not to force gain in flexibility, paying more attention to core-muscle training and to hamstring flexibility. Whether better core muscles and hamstring involvement would improve dance performance remains incompletely explored. Further studies with a larger sized control group could help to quantify the impact of dance training on bone health and to better define the effects of the typical ballet jumps and landings on site-specific bone density.

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