# Cortical and trabecular bone analysis of professional dancers using 3D-DXA: a case–control Study

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# Cortical and trabecular bone analysis of professional dancers using 3D-DXA: a case–control Study

## Abstract

Introduction: Given the lack of relevant data, the aim of this study was to examine femur cortical and trabecular bone in female and male professional ballet dancers.

Material and methods: 40 professional ballet dancers and 40 sex- and age-matched non-exercising controls volunteered. Femoral bone density was scanned by dual-energy X-ray absorptiometry (DXA) scan. A 3D-DXA software was used to analyse trabecular and cortical bone. Anthropometry, maturation (Tanner staging), menstrual parameters (age at menarche and primary amenorrhea), energy availability and nutritional analysis (3-day record) were also assessed.

Results: Compared to non-exercising participants, dancers exhibited significantly higher volumetric density for integral, cortical and trabecular bone, and thicker cortex at the femur. Ballet dancers demonstrated lower body weight compared to controls (p<0.01). Female dancers had their menarche later than controls, and the prevalence of primary amenorrhea were significantly higher in dancers than controls (p<0.01). Dancer’s energy availability was below the normal range (<30 kcal/kgFFM/day).

Conclusions: Despite the presence of certain osteoporosis risk factors such as low energy availability, primary amenorrhoea and lower body weight, professional ballet dancers revealed higher bone density for both cortical and trabecular bone compartments compared to controls.

Keywords: Bone density, DXA, dance training, osteoporosis, athletes

## Introduction

Osteoporosis is characterized by deterioration of bone structure, leading to increased risk of fracture due to bone mass loss (U.S. Department of Health and Human Services, 2004). This condition is more frequent in the elderly and postmenopausal women (NIH Consensus Development Panel on Osteoporosis Prevention, 2001). Several studies have been reporting that exercise (particularly during the growing years) increases bone mineral density (BMD) and prevents osteoporosis in later life (Burrows, 2007; Cadore, Brentano, & Kruel, 2005). Weight-bearing exercise seems to be the most effective physical activity for bone formation enhancement (Matthews et al., 2006; Shanb and Youssef, 2014). However, it appears that exercise affects differently the skeleton depending on the region of the bone; it has been suggested that the effects of weight bearing exercise are more pronounced at cortical than at the trabecular area of the lumbar spine (Mora et al., 1994). However, other studies involving athletes have suggested that exercise affects equally cortical and trabecular areas (Ireland et al., 2013; Wilks et al., 2009). Dancing, for instance, is characterised by high levels of muscular strength, jumps, rapid turns, and high levels of physical fitness (Allen, Nevill, Brooks, Koutedakis, & Wyon, 2013; Angioi, Metsios, Koutedakis, & Wyon, 2009; Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2009; Koutedakis, Frischknecht, Vrbova, Sharp, & Budgett, 1995; Koutedakis and Jamurtas, 2004; Koutedakis et al., 1999; E. Twitchett et al., 2010; E. A. Twitchett, Koutedakis, & Wyon, 2009); these types of movements are known to induce a thicker cortical bone compartment (Nikander et al., 2009). Nevertheless, dancing is also considered an aesthetic activity where low body weight and body characteristics are essential for performance. Literature on the topic suggests that elite dancers may restrict their diet (decreasing energy and/or nutrient intake), which may lead to low body weight and/or negative energy balance (Koutedakis and Jamurtas, 2004). This low energy intake can negatively affect bone, particularly the trabecular bone (Ikedo et al., 2016). Indeed, it has been suggested that trabecular bone is a metabolic compartment, depending mainly on hormonal or metabolic factors (Mora, et al., 1994). Therefore, it seems that dancing has inherent characteristics that may enhance bone formation at cortical areas, but may also negatively affect the trabecular compartment. Studies on dancers' bone health have been showing conflicting results, i.e. some studies suggest that professional dancers have lower BMD compared to controls or normative values, whereas others suggest that professional dancers have higher BMD (Amorim et al., 2015). No studies have been identified thus far reporting cortical and/or trabecular bone mass in elite dancers. However, it has been reported that eumenorrheic non-elite dancers have higher distal tibial trabecular BMD their oligo/amenorrheic counterparts (To, Wong, & Lam, 2005). Studies on other athletic populations show that amenorrheic athletes had lower trabecular volumetric bone mineral density (vBMD) at distal radius compared to non-athletes (similar cortical vBMD was found at the same anatomical site), whereas similar values of both trabecular and cortical vBMD were found at the distal tibia (Ackerman et al., 2012).

Dual Energy X-ray Absorptiometry (DXA) is the most commonly used clinical method of BMD assessment. DXA, however, does not measure the volumetric BMD, but quantifies a 2D areal BMD in a projective image of the bone content. As a result, cortical and trabecular bone cannot be separately assessed. Advanced analytic methods have been proposed for obtaining additional information from standard DXA scans, which, nevertheless, have their own limitations. For example, Hip Structural Analysis (HSA) (Beck, Ruff, Warden, Scott, & Rao, 1990) uses assumptions about the bone geometry and BMD distribution to compute cross-sectional parameters related to bone strength. Trabecular Bone Score (TBS) (Pothuaud, Carceller, & Hans, 2008) is a textural parameter correlated with bone microarchitecture that can be measured in spine DXA scans. Recently, 3D modelling techniques have been proposed to assess the trabecular and cortical bone from hip DXA scans (Humbert et al., 2017; Väänänen, Grassi, Flivik, Jurvelin, & Isaksson, 2015). These "3D-DXA" methods use statistical appearance models together with registration algorithms to model the femur shape and density in 3D and assess both the cortical and trabecular bone from standard hip DXA scans.

The aim of this study is to assess cortical and trabecular bone at the femur in female and male professional ballet dancers using 3D-DXA.

## Methods

### *Participants*

All professional dancers performing in a professional ballet company (full-time dancing; 6-8 hours of training per day, 5 days per week; these dancers started their full-time training at the age of 10) were invited to participate; the total of 42 individuals (68.3%) volunteered. They completed a questionnaire concerning their ethnicity, medical history, and past/current calcium/vitamin D supplementation. Eligible criteria included dancers of white European origin, with no illnesses or treatments that might affect bone metabolism, not taking medication known to affect bone metabolism and no calcium/vitamin D supplementation (one professional dancer was excluded). Women taking oral contraceptives and hormonal therapy were also excluded (one professional dancer). Based on these criteria, the studied population consisted of 40 professional ballet dancers (30 female and 10 male).

Non-exercising participants were also recruited from a local University to act as controls. Eligibility criteria for controls were set according to dancers' characteristics, i.e. same sex, age (defined as decimal age; 12-months difference of a dancer) and race (white European-Caucasian). Exclusion criteria included participation in organised physical activities/sports (i.e. participants were excluded if they were involved in any form of organised exercise). Control participation was also restricted to those who had received/were receiving medications known to affect bone metabolism and/or reported illnesses/treatments that might affect bone metabolism. The total of 40 controls fulfilled the aforementioned criteria.

All participants provided signed informed consent according to the Declaration of Helsinki. The study was approved by the ethics committee of the Regional Administration of Health of Lisbon, Portugal (Proc.063/CES/INV/2012).

### ***Anthropometry, maturation assessment, menstrual, energy expenditure, and nutritional analysis***

Chronological age (obtained as decimal age) and anthropometry measurements were obtained. Height and body weight were measured in t-shirt, shorts and bare feet using a stadiometer (Seca, Seca217 portable stadiometer, Hamburg, Germany) with accuracy of 0.1 cm and an electric scale (TANITA BC-418 MA Segmental Body Composition Analyser; Tanita Corporation, Tokyo, Japan) with an accuracy of 0.1 kg.

All female participants completed a questionnaire to determine age at menarche, regularity of menstrual cycles and consumption of contraceptives. Amenorrhea was defined as the absence of menses for three consecutive months, whereas oligomenorrhea was considered when menstrual cycles occurred at intervals of greater than 35 days.

Energy expenditure and energy intake were only assessed in professional dancers. Professional dancers' energy expenditure was estimated using accelerometer (SenseWear, Bodymedia SenseWear MF Armband Profi-Schrittzähler Fitnesstracker, Germany), the validity and accuracy of which appear elsewhere (Brazeau et al., 2014). Each dancer used the device for 7 consecutive days. The accelerometer was used on the upper right arm for approximately 24-hours. During the same period, nutrient intakes were recorded via a 3-day food diary. Participants were instructed to record all food and beverages consumed during two week days and one weekend day following appropriate instructions. The software Food Processor SQL Edition, version 9.8.1 was used to estimate average energy and calcium intakes. Energy availability was further estimated using standard protocols (http://www.femaleathletetriad.org/calculators/); information on dietary energy intake (provided by the food diary), exercise energy expenditure (information retrieved from the accelerometer), and body fat percentage (measured by DXA) was used to estimate energy availability.

### ***Bone mass measurements***

BMD (g/cm$^2$) and bone mineral content (BMC) (g) were determined using DXA. Hip DXA scans were administered to assess bone parameters at the proximal femur, and total body DXA scans were used to estimate fat mass and lean mass. All DXA scans were performed using a GE Lunar Prodigy (GE Medical Systems, Madison, WI) and ENCORE software (version 12.3, Prodigy; Lunar Corp, Madison, WI). The coefficients of variations measured in our centre was 1.0% for both total femur BMD and total body. The same certified technician performed all DXA scans.

### 3D-DXA modelling

3D-DXA software (version 2.2, Galgo Medical) was utilised to assess trabecular macrostructure and cortex of all participants (both professional dancers and controls). This software uses a statistical shape and density model of the proximal femur built from a database of Quantitative Computed Tomography (QCT) images. The algorithm registers the 3D statistical model onto the DXA scan to obtain a 3D participant-specific model of the proximal femur shape and BMD distribution. The cortical thickness and density was computed by fitting a function of the cortical thickness and density, location of the cortex, density of surrounding tissues, and imaging blur to the density profile computed along the normal vector at each node of the proximal femur surface mesh (Humbert, Martelli, et al., 2017). Figure 1 shows the main steps of the modelling process and the software interface. The vBMD, BMC and volume can be computed at the total femur (union of the neck, trochanter and shaft) region of interest for the trabecular, cortical and integral (trabecular and cortical) bone. The mean cortical thickness was computed at the total femur region of interest. The accuracy of models and measurements provided by the 3D-DXA software algorithm was evaluated against QCT in previous work (Humbert, Martelli, et al., 2017). Briefly, integral, trabecular, and cortical vBMD computed by QCT and 3D-DXA at total femur have shown correlation coefficients of 0.95, 0.86, and 0.93, respectively. The correlation coefficient between cortical thickness computed by 3D-DXA and QCT at total femur was 0.91. The method was evaluated in men and women with normal bone density, osteopenia and osteoporosis (mean age of 57.5 ± 13.5 years [23 years–91 years]). The least significant changes (LSC) for the 3D-DXA measurements (evaluated in postmenopausal women) were 16.8 mg/cm3 for the integral vBMD, 15.5 mg/cm3 for the trabecular vBMD, 16.6 mg/cm3 for the cortical vBMD (total femur), and 0.057 mm for the cortical thickness (Humbert, Di Gregorio, & Del Rio, 2017).

### *Statistical analyses*

3D-DXA and DXA measurements were computed for all participants (professional dancers and controls); unpaired two-sample t-test was used, after checking for normality, to compare measurements between groups. In case significant differences were found between participant characteristics (age, weight or height), the variables were treated as potential confounding parameters. ANCOVA was used to compare density measurements between groups after adjusting for confounding variables. ANCOVA was used to analyse the differences after adjusting for confounding variables. Average cortical thickness and density mapping were generated for both groups. The statically significance of the differences found at each vertex of the femoral shape was analysed using Student's t-test. To compare the volumetric densities of both groups, the average 3D-DXA density instance was computed for each group and registered onto the average femoral shape for the group. A frontal slice was computed for each group for comparison purposes. The R 3.3.2 software (www.r-project.org) was used for all statistical analyses, whilst the statistical significance was set at $p<0.05$.

## Results

Descriptive general characteristics of all participants appear in Table 1. Professional ballet dancers demonstrated similar age and height, but showed significantly lower body weight ($p<0.01$) and fat mass ($p<0.001$) compared to controls. Also, dancers' age at menarche and primary amenorrhea were significantly higher than controls (p<0.01). Energy intake and energy availability in dancers were 1728.8 ± 607.9 Kcal/day and 26.9 ± 15.4 kcal/kgFFM/day, respectively.

3D-DXA and DXA measurements are shown in Table 2. Since a significant difference was found between professional dancers and controls regarding body weight, this variable was included as a potential confounding parameter. Professional dancers revealed significantly higher vBMD than controls (8.1% higher; $p=0.036$, without adjusting for body weight). Specifically, both cortical and trabecular vBMD were significantly increased in dancers compared to controls (12.4% higher, $p=0.016$ and 2.3% higher, $p=0.037$, respectively). Compared to controls, professional dancers had a thicker femoral cortex (5.4% thicker, $p=0.046$). After the adjustment for body weight, all measured bone parameters (both DXA and 3D-DXA outcomes) showed significant differences between dancers and controls ($p<0.05$; Table 2). The anatomical distribution of the differences in cortical thickness and density between dancers and controls is displayed in Figure 2. The mean frontal slice computed for dancers and controls, as well as a difference image between both groups can be seen in Figure 3.

## Discussion

Existing literature has revealed rather conflicting results on professional dancers' bone health, i.e. some studies highlight that dancers have low BMD, whereas others show that dancers have greater BMD compared to controls. To our knowledge, this is the first study investigating volumetric parameters at the femur (impact site) in a sample of female and male professional ballet dancers. Using 3D-DXA, we found evidence that, compared to non-exercising participants, professional ballet dancers displayed higher vBMD for integral, cortical and trabecular bone, and thicker cortex at the femur. This might indicate that professional dancing is capable of inducing bone mass gains at both cortical and trabecular level, even in the presence of a relatively low energy availability.

It is general believed that both female and male elite athletes are at risk for a relative energy deficiency in sport (RED-S) (Mountjoy et al., 2014). Indeed, it has been recently suggested that energy deficiency in relation to energy intake and energy expenditure balance is a main factor that triggers several health concerns, including low bone mass (Mountjoy, et al., 2014). The energy imbalance that elite athletes may experience can affect negatively the hypothalamus, decreasing the circulating levels of certain bone-related hormones, hindering further bone mineralization (Locatelli and Bianchi, 2014). Accordingly, the training loads that typically will enhance bone formation in elite athletes may be annulled due to the presence of low energy availability and other well-known osteoporosis risk factors such as low body weight and menstrual disturbances. The spectrum of low energy availability, low body weight and, consequently, low BMD may mainly affect participants involved in aesthetic sports whereas body characteristics are essential for performance (Maimoun, Georgopoulos, & Sultan, 2014). Indeed, previous studies demonstrated that athletes in aesthetic sports who experience amenorrhea (Robinson et al., 1995) and have low energy availability may also have relatively low BMD (Valentino et al., 2001). It has been showed that amenorrheic athletes have lower BMD than eumenorrheic athletes (Ackerman, et al., 2012; Rencken, Chesnut, & Drinkwater, 1996; Russell et al., 2009), and, consequently, impaired bone microarchitecture (Ackerman et al., 2011; Micklesfield, Lambert, Fataar, Noakes, & Myburgh, 1995; Tomten, Falch, Birkeland, Hemmersbach, & Hostmark, 1998). In fact, energy availability of our professional ballet dancers was below the normal range (i.e. <30 kcal/kgFFM/day), and their body weight was significantly lower compared to controls. Further, the presence of primary amenorrhea, a well-known osteoporosis risk factor, was significantly increased in female dancers compared to matched controls. However, despite the presence of the aforementioned osteoporosis risk factors, professional ballet dancers' bone mass was higher compared to sex- and aged-matched controls. Unlike previous studies, this finding may indicate that dance training stimuli is sufficient to counterbalance the potential negative effects of low energy availability, low body weight and menstrual disturbances. Indeed, if these risk factors were negatively affecting BMD in our professional ballet dancers, it would be expected to find lower trabecular bone compared to controls as it has been reported that this type of bone is a metabolic compartment, more sensitive to hormonal imbalance (Mora, et al., 1994). Interestingly, the present study shows that professional dancers revealed higher trabecular and cortical areas than controls. This suggests that dance training might be able to induce bone anabolic adaptations at both trabecular and cortical compartments. This is in line with available data on other athletic populations showing that exercise is capable of inducing BMD gains in both cortical and trabecular areas (Ireland, et al., 2013; Wilks, et al., 2009). It has also been reported that femoral neck strength at the superolateral area is the most relevant in fall-related fractures (Fuchs et al., 2017). Our professional dancers revealed higher density in this area compared to controls, which might indicate reduced risk of fractures.

It is difficult to compare the present findings with those from other studies as the majority of the published reports have not examined volumetric bone mass parameters in dancers (Burckhardt, Wynn, Krieg, Bagutti, & Faouzi, 2011; Hoch et al., 2011; Khan et al., 1996; Matthews, et al., 2006; Robinson, et al., 1995); however, recent studies showed that professional ballet dancers (both female and male) have higher BMD at the femur compared to matched controls (Amorim, Koutedakis, et al., 2017; Amorim, et al., 2015; To, et al., 2005). Using micro-finite element analysis applied to high-resolution MRI, it was found that modern dance students (female) have higher trabecular bone stiffness at the distal femur compared to controls, suggesting a better adaptation to exercise stimuli of the trabecular bone compartment rather than the cortical bone (Chang et al., 2013). However, this study examined modern dance students. Due to differences in training regiments, selection criteria and training loads, findings in modern and collegiate dance students might not be transferable to professional ballet dancers. Indeed, unlike our dancers and collegiate dancers, modern dance students did not revealed any osteoporosis risk factor (Chang, et al., 2013).

The fact that our dancers demonstrated significantly higher cortical and trabecular BMD at the femur does not exclude the possibility of a relatively low BMD at other anatomical sites. It has been previously demonstrated that female professional ballet dancers have lower BMD at the forearm (non-impact site) compared to general population (Amorim, Koutedakis, et al., 2017). The same phenotype has also been reported in relation to vocational dance students at the forearm and lumbar spine (impact spine) (Amorim, Koutedakis, et al., 2017; Amorim, Metsios, et al., 2017). The longitudinally assessment of cortical and trabecular BMD at the aforementioned anatomical sites (particularly at the lumbar spine as it is mainly constituted by trabecular bone) would provide insights on how bone mass changes as dancers receive dance training stimuli. Furthermore, it would also be of interest to report prevalence estimates of low energy availability and low body weight, given that the report as mean ± SD does not allow discrimination of the true number of cases with osteoporosis risk factors.

The present study showed differences in cortical thickness and density between the view anterior and posterior femur in both dancers and controls. One potential explanation for these observations might be the fact that quadriceps muscles are more often recruited during daily activities than hamstrings. This frequent activation of the quadriceps might induce pressure forces at the anterior femur unlike the posterior femur, increasing further bone formation at the anterior face. In fact, research has shown that quadriceps muscles are stronger than hamstrings for both non-athlete and athletic populations (Jung, Lee, Seo, & Song, 2017; Smidt, 1973; Sundby and Gorelick, 2014; Zvijac, Toriscelli, Merrick, Papp, & Kiebzak, 2014).

The use of 3D-DXA could be insightful to monitor athletes, as it provides information on the cortical and trabecular bone at an impact site. Nevertheless, the present study has also some limitations regarding its methodology. 3D-DXA is a modelling technique which is not as accurate as direct measurement techniques, such as QCT or pQCT (at the tibia or radius). Further, the accuracy of 3D-DXA analyses has not been specifically evaluated for elite dancers. Nevertheless, a previous study showed that 3D-DXA provides accurate data for young healthy population (male and female), compared to QCT (Humbert, Martelli, et al., 2017). Furthermore, differences in integral BMC measured by 3D-DXA between professional dancers and controls were higher than those found from DXA (12.6% and 5.1%, respectively). The difference between BMC measurements obtained using the two techniques might be related to the definition of the regions of interest. The 3D-DXA total femur region was defined over the 3D subject-specific femoral shapes, while the DXA total femur region was identified in the DXA scan. Another limitation of the present study is its cross-sectional design, which means that causality cannot be established. The use of a self-reported questionnaire to assess nutrition intake, as well as the lack of data on energy intake and availability in controls, are further limitations of the present study. The studied population mostly consisted of females (n=29). The small number of male participants (n=11) did not allow us to conduct meaningful statistics on this sub-cohort. However, preliminary analyses showed that the male and female professional dancers of our cohort, when studied separately, had higher areal bone mineral density, higher vBMD in the cortical, trabecular and integral compartments, and thicker cortex, compared to controls, following the trends observed for the entire cohort. Finally, we did not recorded fractures or injuries among our dancers. However, in order to establish the clinical significance of our findings, it would be of great interest for future studies to report the association between low BMD and dance injuries.

## Conclusion

Elite ballet dancing does not appear to have a deleterious effect on bone health. Regardless of the presence of low energy availability and low body weight, professional ballet dancers have higher BMD for both cortical and trabecular bone compartments. This might indicate that professional dance training stimuli may counterbalance the potential deleterious effects of the presence of osteoporosis risk factors at the femur (impact site). Future studies should assess other impact (lumbar spine) and non-impact (forearm) sites using longitudinal models.

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## Disclosure statement

Ludovic Humbert is a stockholder at Galgo Medical.

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Table 1. General characteristics of the studied participants.

Table 2. Unadjusted and adjusted DXA and 3D-DXA parameters of total femur.

Figure 1. 3D-DXA modelling process and software interface. A) Registration of the 3D statistical model onto the hip DXA scan, attained by maximising the similarity between the projection of the model and the DXA image. B) Measure density variations along the normal vector at each node of the femur surface, and estimate cortical thickness and density by fitting of a function of location of the cortex, density of surrounding tissues, and imaging blur to the measure density variations. C) Software interface showing the anatomical distribution of the cortical thickness.

Figure 2. Differences in cortical thickness (mm, top left, and percentage, top right) and cortical density (mg/cm$^3$, bottom left, and percentage, bottom right) between professional dancers and controls. Colour-coded regions indicate statistically significant differences. Regions with no significant differences are left in grey.

Figure 3. Front slice showing the average vBMD values in controls (left) and professional dancers (middle), and average differences between both groups (right) displayed only for the trabecular bone. The contour of the average shape in the control group is shown in purple (right).