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Bone mineral density in vocational and professional ballet dancers

Tânia Amorim, MSc^{1,2}, Yiannis Koutedakis, PhD^{2,3}, Alan Nevill, PhD², Matthew Wyon, PhD^{2,4}, José Maia, PhD¹, José C. Machado, PhD⁵, Franklim Marques, PhD⁶, George S. Metsios, PhD^{2,3}, Andreas D. Flouris, PhD³, Nuno Adubeiro, MSc⁷, Luísa Nogueira, PhD⁷, Lygeri Dimitriou, PhD⁸

¹Centre of Research, Education, Innovation and Intervention in Sport, Faculty of Sports, University of Porto, Porto, Portugal

²Faculty of Education, Health and Wellbeing, University of Wolverhampton, Walsall, UK

³School of Sports and Exercise Sciences, University of Thessaly, Trikala, Greece

⁴National Institute of Dance Medicine and Science, UK

⁵i3S - Instituto de Investigação e Inovação em Saúde, Universidade do Porto, Portugal

⁶Faculty of Pharmacy, University of Porto, Porto, Portugal

⁷School of Health Technology of Porto, Polytechnic Institute of Porto, Porto, Portugal

⁸London Sport Institute, Middlesex University, London, UK

Corresponding author:

Tânia Amorim

Centre of Research, Education, Innovation and Intervention in Sport.

Faculty of Sports, University of Porto

Rua Dr. Plácido Costa 91

4200 – 450 Porto, Portugal

tania_amorim@hotmail.com

39 **SUMMARY**

40 According to existing literature, bone health in ballet dancers is controversial. We have verified that, compared to
41 controls, young female and male vocational ballet dancers have lower bone mineral density (BMD) at both impact
42 and non-impact sites, whereas female professional ballet dancers have lower BMD only at non-impact sites.

43

44 **ABSTRACT**

45 *Purpose:* The aims of this study were to a) assess bone mineral density (BMD) in vocational (VBD) and professional
46 (PBD) ballet dancers, and b) investigate its association with body mass (BM), fat mass (FM), lean mass (LM),
47 maturation and menarche.

48 *Methods:* The total of 152 VBD (13±2.3yrs; 112 girls, 40 boys) and 96 controls (14±2.1yrs; 56 girls, 40 boys), and
49 184 PBD (28±8.5yrs; 129 females, 55 males) and 160 controls (27±9.5yrs; 110 female, 50 males) were assessed at
50 the lumbar spine (LS), femoral neck (FN), forearm and total body by Dual-energy X-ray absorptiometry. Maturation
51 and menarche were assessed via questionnaires.

52 *Results:* VBD revealed lower unadjusted BMD at all anatomical sites compared to controls ($p<0.001$); following
53 adjustments for Tanner stage and gynaecological age, female VBD showed similar BMD values at impact sites.
54 However, no factors were found to explain the lower adjusted BMD values in VBD (female and male) at the forearm
55 (non-impact site), nor the lower adjusted BMD values in male VBD at the FN. Compared to controls, female PBD
56 showed higher unadjusted and adjusted BMD for potential associated factors at the FN (impact site) ($p<0.001$) and
57 lower adjusted at the forearm ($p<0.001$). Male PBD did not reveal lower BMD than controls at any site.

58 *Conclusions:* Both females and males VBD have lower BMD at impact and non-impact sites compared to control,
59 whereas this is only the case at non-impact site in female PBD. Maturation seems to explain the lower BMD at
60 impact sites in female VBD.

61

62 **KEYWORDS:** bone mass; prevalence; associated factors; elite dance; ballerinas

63

64 **INTRODUCTION**

65 Osteoporosis and osteopenia [i.e. low bone mineral density (BMD)] are recognised as the most frequent bone
66 disorders, linked to high treatment costs and limited quality of life due to osteoporotic fractures [1, 2]. Hence, the
67 identification of those at high-risk is crucial for planning appropriate prevention programmes. The diagnosis of low
68 BMD in premenopausal women and children is based on the International Society of Clinical Densitometry (ISCD)
69 guideline, whereas a diagnosis is confirmed when BMD values lie within 2.0 standard deviations (SD) or more
70 below the average value [3]. The American College of Sports Medicine (ACSM) has proposed different guidelines
71 for the diagnosis in athletes. The term “low BMD” is used for BMD values between -1.0 and -2.0 SD, and the term
72 “osteoporotic” for BMD equal or less than -2.0 SD (along with secondary risk factors for stress fractures) [4].

73 Low BMD has been traditionally associated with elderly and postmenopausal women [5], though some
74 athletic populations, as endurance athletes, might also be at increased risk [6, 7]. In ballet dancers, however, aspects
75 regarding low BMD remain ambiguous [8]. While some authors underline the negative effects of professional dance
76 training on bone metabolism (e.g. lean body type required for performance) [9-11], others suggest that the
77 mechanical impact from dancing may provide a protection against low BMD, particularly at impact sites [12-14]. For
78 instance, the high levels of muscular strength required for technical performance and weight-bearing activity
79 associated with jumping may stimulate bone-forming cells [12-14]. Nevertheless, most of the relevant publications
80 on ballet dancers have been categorised average of low quality [8]. Therefore, the aims of the present study were a)
81 to assess BMD in vocational (VBD) and professional ballet dancers (PBD), and b) to investigate the association
82 between BMD with body mass (BM), fat mass (FM), lean mass (LM), menarche and maturation.

83
84 **METHODS**

85 **Study population**

86 This study was conducted by inviting active students from vocational dance schools (children undergoing 4-8 hours a
87 day dance training in order to prepare for the profession) and active dancers from professional ballet companies.
88 Pilot studies were administrated at a vocational dance school and a professional ballet company in order to calculate
89 the sample size needed for prevalence estimate; sex and aged matched controls were also included in both cases. In a
90 sample of 36 female VBD and 36 matched-controls, low BMD (Z-score of <-2.0) at the lumbar spine (LS) was found
91 in 36% and 6%, respectively. Based on this finding, we estimated that 37 participants were needed in each group to
92 obtain 90% power, with $\alpha=0.05$. Similarly, in a sample of 22 female PBD (22 matched-controls) and 10 male PBD
93 (10 matched-controls), the prevalence of low BMD (Z-score of -1.0) at the LS was found to be 32% (vs. 5%) in
94 female PBD and 20% (v. 0%) in male PBD. We subsequently estimated that 42 female participants and 46 male
95 participants in each group were needed to reach significance (90% power, $\alpha=0.05$). Assuming participants’ non-
96 response and possible dropouts, we approached two vocational dance schools and four professional ballet companies.

97 To recruit participants, an introductory letter briefly explaining the purposes of the study was initially
98 forwarded to the executive boards of the dance schools and companies. Following boards’ agreement, the research
99 team contacted the VBD (their guardians too) and PBD to present them with the studies aims and methodologies.
100 From the total of 595 participants (360 VBD and 235 PBD), 158 VBD and 206 PBD volunteered. From this cohort,
101 those who had received or were receiving medications known to affect bone metabolism were excluded (one PD),
102 together with those receiving calcium supplements (two VD and one PD). Given the differences in bone mass values
103 between individuals from different races [15], only participants referring themselves as white European-Caucasian
104 dancers were included. Based on these criteria, the total of 152 VBD (13±2.3yrs; 112 girls, 40 boys) and 184 PBD

105 (28±8.5yrs; 129 females, 55 males) were finally included in this study. Participants provided details on physical
106 exercise (hours per week). Female and male VBD reported to perform 18.2±7.0 and 19.5±7.2 hours per week of
107 dance training, respectively. Female and male PBD reported 32.9±8.4 and 32.5±9.6 hours per week of dance
108 training, respectively. Details of the recruited dance population and its participation rate appear in Figure I.

109 Controls were also included in this study. Controls for the VBD were recruited from two local state schools,
110 while controls for PBD were recruited from two local state universities. Eligibility criteria for controls were set
111 according to dancers' characteristics, i.e. controls were only considered eligible if they were of the same sex, age
112 (defined as decimal age; 12-months difference of a dancer) and race (white European-Caucasian). Exclusion criteria
113 included current and previous participation in regular and organised physical activities. This rule did not apply to
114 children participants involved in physical education sessions at their school. Control participation was also restricted
115 to those who had received or were receiving medications known to affect bone metabolism. All participation criteria
116 explaining the purpose for the recruitment was advertised via email and letters, following consent from the respective
117 boards of directors. Out of the 282 responses (105 pupils, 177 university students), 256 fulfilled the current criteria
118 and were included in the study [controls for VBD: 96 (14±2.1yrs), 56 girls, 40 boys; controls for PBD: 160
119 (27±9.5yrs), 110 female, 50 males]. Female and male controls for VBD were involved in 2.4±0.5 and 2.1±0.4 hours
120 per week of physical exercise, consisting mainly of school physical education. Female and male PBD controls did
121 not report extra physical exercise apart from daily life routines. Details of the recruited controls and its participation
122 rate appear in Figure II.

123 All participants provided signed informed consent. Following that, they underwent anthropometric
124 measures, completed a menstrual questionnaire and participated in bone/body composition measurements (Figure 1).
125 All procedures were approved by the NHS Health Research Authority, UK (Proc.14/WM/0008 and 14/WM/0009)
126 and by the ethics committee of the Regional Administration of Health of Lisbon, Portugal (Proc.063/CES/INV/2012)
127 in accordance with the Helsinki Declaration.

128 **Anthropometry measurements, menstruation, smoking, nutrition intake, hormonal analysis and pubertal** 129 **assessment**

131 Chronological age was obtained as decimal age (date of birth minus measurement date). Participants' height (m),
132 sitting height (m) and BM (kg) were measured using standard stadiometers (Seca) and digital scales (Tanita),
133 respectively. BM index (BMI) was calculated as kilograms per square meter (kg.m^{-2}). Female participants completed
134 a questionnaire to determine age at menarche. Total lifetime menses (number of menses since menarche to current
135 age) were calculated as previously described [16]. Primary amenorrhea was defined as the absence of menarche by
136 the age of 15 [17]. Gynaecological age (years) was calculated from the year of menarche to the age at which data
137 were collected – current age [18].

138 Participants were asked to report their smoking history habits. Nutrient intakes were recorded via a
139 validated 3-day food diary (two weekdays and one during weekend) [19]; this information was only assessed in VBD
140 and their controls. The Food Processor SQL Edition, version 9.8.1 was used to estimate average energy, calcium and
141 vitamin D intakes.

142 Blood samples were collected in early morning after an 8-hour fasting. Serum insulin-like growth factor-1
143 (IGF-1) was measured by immunoradiometric assay kit (IRMA, IMMUNOTECH SAS, Marseille, France), in an
144 automated analyser (Wallac Wizard 1470, Finland). The assay ranges were from 2 to 1.200ng/mL). The intra-assay
145 and inter-assay CV's were below or equal to 6.3% and 6.8%, respectively. Blood samples were centrifuged at 2500g

146 for 10 min and serum stored at -80°C until analyses. Finally, pubertal development in VBD and their controls were
147 self-reported using the Tanner sexual staging questionnaire [20].

148

149 **Body composition and bone measurements**

150 BMD at the LS, femoral neck (FN) and forearm (1/3 distal radius) were measured using Dual-energy X-ray
151 absorptiometry (DXA). Body composition was assessed through a DXA whole-body scan [FM and LM (Kg)]. As
152 participants were from different regions, two different DXA devices were used [Hologic (Discovery Wi) and Lunar
153 (GE Lunar Prodigy)]. The total of 68 (44.7%) VBD and 178 (96.7%) PBD were subjected to Lunar scans device
154 while the remaining 84 (55.3%) VBD and 6 (3.3%) PBD were scanned using Hologic. In addition, 20 (27.1%)
155 children controls and 110 (68.8%) adult controls were assessed on a Lunar device vs. 70 (72.9%) and 50 (31.2%) on
156 Hologic, respectively.

157 It is known that Lunar and Hologic BMD measurements demonstrate high correlation values between them
158 [21, 22]. It is also known that there is a tendency for Lunar model to inflate BMD values compared to Hologic [22].
159 Therefore, besides the daily calibration required from each DXA manufacturer, cross-calibration of the two scanners
160 was also conducted on a group of 20 men and women; the age of these 20 participants covered the age-range of the
161 entire sample (both dancers and controls) used for the purpose of the present study. The 20 participants were
162 measured with both Lunar and Hologic within a period of 5 days. Subsequently, regression equations using BMD
163 from Lunar as dependent variable and BMD from Hologic as independent variable were performed taking into
164 account cross-calibration. The correlation between the two DXA models were high (forearm BMD: $r=0.96$, adjusted
165 $r^2=0.93$, std. error of estimate=0.03; LS BMD: $r=0.96$, adjusted $r^2=0.92$, std. error of estimate=0.05; FN BMD:
166 $r=0.97$, adjusted $r^2=0.93$, std. error of estimate=0.05). The Hologic BMD data were further converted to the Lunar
167 data using the following equations: Forearm BMD Lunar = $-0,085263 + 1,356535 * \text{Hologic}$; LS BMD Lunar =
168 $0,030762 + 1,161805 * \text{Hologic}$; FN BMD Lunar = $0,084782 + 1,116509 * \text{Hologic}$. Following the BMD adjustments,
169 Z-scores at each anatomical site were further calculated for VBD considering standard data reference ranges for
170 gender and age provided by the Lunar manufacture (BMDCS data reference for children adjusted for height).

171

172 **Statistical analyses**

173 Independent t-tests were used to compare general characteristics between dance population and controls. Chi-square
174 test was adopted to determine whether there is a significant difference in the distribution of Tanner stages between
175 VBD and controls. Chi-square analyses were further employed to examine prevalence differences of low BMD
176 between VBD (stratified by sex) and their controls. Analysis of covariance (ANCOVA) was conducted in VBD and
177 PBD (also stratified by sex) in order to identify potential associated factors that might explain differences in BMD
178 between groups (i.e. VBD*matched controls, and PBD*matched controls). Consequently, BMD at each anatomical
179 site (dependent variable) was adjusted for: BM, FM, LM, Tanner stage, age at menarche, gynaecological age, and
180 energy intake (covariates were entered as separate constituents). However, prior to the aforementioned analysis, all
181 BMD data were controlled for school/company and/or DXA effect, since our dancers were recruited from a) different
182 ballet schools/companies and b) were scanned using two DXA devices. Missing data were identified as “system
183 missing” using the SPSS software - version 20.0. We had missing data for FM (7.9% and 8.2% in VBD and PBD,
184 respectively) and nutrition intake (15.1% and 18.8% in VBD and controls, respectively). Statistical significance was
185 set at $p<0.05$.

186

187 **RESULTS**

188 Table I depicts the general characteristics of all participants. Table I indicates that maturity differences between
189 dancers and controls are more pronounced in female VBD than their male counterparts. Compared to controls,
190 female and male VBD revealed significantly lower BM (by 10.8kg and 11.1kg, respectively; $p<0.001$), BMI (by
191 4.4kg/m^2 and 3.6kg/m^2 , respectively; $p<0.001$) and FM (by 9.0kg and 8.0kg, respectively; $p<0.001$). In female VBD,
192 age of menarche was ~18 months later than controls ($p<0.001$). Similarly, female and male PBD revealed
193 significantly lower BM (by 9.2kg and 6.0kg, respectively; $p<0.001$) and BMI (by 3.9kg/m^2 and 2.0kg/m^2 ,
194 respectively; $p<0.001$) compared to controls. Female PBD also demonstrated significantly lower FM (by 10.3kg,
195 $p<0.001$) and higher LM (by 2kg, $p<0.01$) compared to controls, and had their menarche approximately two years
196 later than controls ($p<0.001$). There was no significant difference between VBD and controls for calcium and
197 vitamin D intake, but both female and male VBD consumed significantly less calories per day compared to controls
198 (by 215.1kcal/day or 13.2% and 278.0kcal/day or 17.4%, respectively, $p<0.05$). Serum IGF-1 concentrations were
199 not significantly different in VBD compared to controls. Table I also depicts unadjusted BMD values for potential
200 associated factors (i.e. BMD data were only adjusted for DXA-device and school/company). Both female and male
201 VBD show significantly lower unadjusted BMD values for potential associated factors at all measured anatomical
202 sites compared to controls ($p<0.001$). However, female PBD demonstrate significantly higher unadjusted BMD at the
203 FN (by 11.9%, $p<0.001$), and significantly lower at the forearm (by 13.9%, $p<0.001$). Male PBD show significantly
204 higher unadjusted BMD values than controls at the FN (by 15.9%, $p<0.001$) and LS (by 10.3%, $p<0.01$).

205 Tables II and III depict the ANCOVA results for VBD and PBD, respectively. In particular, Table II
206 illustrates that both female and male VBD have significantly lower adjusted BMD values at all anatomical sites
207 compared to controls. BM, LM, FM, and energy intake were positively associated with BMD in female VBD at the
208 FN ($p<0.001$, $p<0.001$, $p<0.01$ and $p<0.05$, respectively). However, these covariates did not explain group
209 differences (i.e. VBD versus controls); only when controlling for Tanner stage and gynaecological age BMD
210 differences between groups were dissipated. The factors determining BMD differences between VBD and their
211 matched controls at the LS were Tanner stage (females and males both at $p<0.001$) and body mass (only for males,
212 $p<0.001$). No factors were detected to explain the lower adjusted BMD values in VBD (both in female and male) at
213 the forearm (non-impact site) than controls, nor the lower adjusted BMD values in male VBD at the FN (impact site).
214 Table III confirms that our female PBD have higher adjusted BMD values at the FN ($p<0.001$), and lower adjusted
215 BMD values at the forearm ($p<0.001$) than controls. LM and gynaecological age were positively associated with
216 these findings at the FN ($p<0.05$, $p<0.001$, respectively); the fact that our female PBD had their menarche later than
217 controls seems to explain the BMD differences between groups at the forearm ($p<0.001$). FM is positively associated
218 with BMD at the LS in female PBD ($p<0.01$). Male PBD revealed higher adjusted BMD at impact sites than controls
219 (FN and LS), and similar BMD values at the forearm; LM is positively associated with these findings at the LS
220 ($p<0.01$).

221 Table IV shows the prevalence of low BMD in VBD ($Z\text{-score} < -2.0$). Significantly higher prevalence of
222 low BMD at the forearm (9.2% vs. 0%, $p=0.01$) and LS (16.4% vs. 5.5%, $p<0.05$) was noted in female VBD
223 compared to controls. Although not significant, the proportion of cases with low BMD was higher in male VBD at
224 all anatomical sites compared to controls.

225
226
227

228 **DISCUSSION**

229 Data on BMD in dancers has been ambiguous thus far. This is supported by a recent systematic review highlighting
230 the need for further research on the field [8]. To our knowledge, the present study is the first to compare BMD values
231 in a relatively large cohort of both vocational and professional ballet dancers. We found that female and male VBD
232 have lower BMD values compared to matched-controls at both impact (FN and LS) and non-impact sites (forearm).
233 It is noteworthy that the proportion of cases with low BMD (Z -Score < -2.0) in female VBD was significantly higher
234 compared to controls at both impact (LS) and non-impact sites (forearm); although not significant, male VBD
235 demonstrated higher prevalence of low BMD at all three assessed anatomical sites. Nevertheless, after adjusting
236 BMD for maturation markers (Tanner stage and gynecological age), we found similar values at impact sites (both FN
237 and LS) in female VBD. This means that BMD differences between groups at these sites can be explained by the fact
238 that our female VBD dancers are late matures compared to controls. However, maturation markers did not explain
239 the lower BMD displayed by VBD (both female and male) at non-impact sites compared to controls, nor the lower
240 BMD in male VBD at the LS. Considering female PBD, we found significantly higher unadjusted and adjusted BMD
241 values at impact sites (FN) and significantly lower BMD at the forearm compared to matched controls. These
242 findings suggest that weight-bearing exercise might be able to improve BMD despite a relatively low BM, an
243 indication that such exercise might be able to override any potential negative effect. A similar result has been
244 obtained for male PBD who did not reveal lower BMD compared to controls at any site. The latter confirms previous
245 data [23] and could be partly explained by the fact that males have less pronounced endocortical resorption and
246 higher periosteal expansion compared to females [24].

247 Dancing has been considered as a weight-bearing activity [13]. Studies using weight-bearing physical
248 activities have shown positive effects on bone mineral accrual in both adults and children [25, 26]. Indeed, it has
249 been suggested that 60 min x 3 a week of weight-bearing exercise is sufficient to prevent low BMD in general
250 population [27]. Since our participants were vocational and professional dancers, they were involved in daily classes
251 of several hours of weight-bearing activity [28, 29]. Considering data on bone cell biology and function of osteocytes
252 as mechanosensory cells [30, 31], it would be expected to find significantly higher BMD values at impact sites
253 (particular FN) and similar BMD values at non-impact sites compared to controls. However, dancing is also an
254 aesthetic activity whereas body size is essential for performance. This requirement might place dancers at risk for
255 low BM, a well-known risk factor for low bone mass phenotypes. Indeed, in our study, both VBD and PBD had
256 significantly lower BM values compared to their controls. Further, compared to matched controls, female PBD also
257 revealed higher prevalence of primary amenorrhea (and latter age at menarche), another well-known osteoporosis
258 risk factor. Nevertheless, the fact that female PBD showed higher BMD at impact sites compared to controls
259 suggests that dance training is able to stimulate BMD gains, even in the presence of osteoporosis risk factors. Indeed,
260 female PBD only revealed lower BMD values compared to non-exercising controls at the forearm (non-impact site),
261 which might indicate that exercise (dance training) can counterbalance the potential negative effects of osteoporosis
262 risk factors at loading sites. However, it seems such a compensatory effect could not be seen in VBD since they
263 demonstrated significantly lower bone mass at all studied anatomical sites. Actually, the prevalence of low BMD at
264 the forearm and LS was also significantly higher in female VBD compared to controls. As LS is mainly constituted
265 by trabecular bone (known to be more sensitive to mechanical stress from exercise [32]), and as ballet dancing
266 requires high levels of muscular strength (placing considerable mechanical stress on lower back [28, 33]), it would
267 not be expected to find a significantly higher number of cases with low BMD at this anatomical site compared to
268 controls. It seems logical to suggest maturation as the reason for these findings in female VBD. Indeed, a

269 disproportionately high number of VBD were at Tanner stage I compared to controls, which might indicate that
270 dancers are late matures. Delayed puberty has been linked with low BMD in children and adolescents [34]. Further,
271 maturation markers (i.e. Tanner stage and gynaecological age) seem also to explain the differences in BMD at the
272 FN in female VBD. This finding is not surprising due to selection criteria for professional dance training; children
273 have to go through auditions for a place in a vocational dance school, where specific body stereotypes (small body
274 size; ecto-mesomorphic body type) are essential for acceptance [35]. However, although maturation seems to explain
275 the group differences in BMD at impact sites, this is not the case when the forearm (non-impact site) is considered.
276 Indeed, in line with available data [10, 18, 36, 37, 38, 39], age at menarche, together with BM, LM FM, and energy
277 intake, were significantly associated with BMD at the forearm; nevertheless, these factors seem not to explain BMD
278 differences between female VBD and controls at this anatomical site. Considering male VBD, the present study did
279 not find factors to explain the lower BMD values compared to controls at both impact (FN) and non-impact sites.
280 Previous studies usually focus in female dancers as it is generally accepted that females have increased odds for low
281 BMD. However, the present study suggests that young male dancers may also be at risk for low BMD. Future studies
282 should also consider young male dancers in relation to BMD in different settings. Further, factors such as low
283 energy availability, genetics and/or hormonal levels should be considered in future studies, given their association
284 with low bone mass phenotypes [4, 40].

285 The current results regarding BMD in VBD might be of concern, as young dancers may enter adulthood
286 with relatively low BMD, which may further impair the peak bone mass attainment [41]. Delayed puberty has been
287 reported to be associated with lower IGF-1 levels and low bone mass in children and adolescents [34]; interestingly
288 though, serum IGF-1 was not significantly different between VBD and controls (both in female and male), despite
289 the difference seen in Tanner staging. Nevertheless, findings in children should be interpreted with caution due to
290 biological changes which occur during growth [41]. Longitudinal studies should be conducted in VBD to ascertain
291 how bone mass changes throughout growing.

292 The clinical significance of low BMD lies on the increased risk of fracture [3, 4]. We did not record
293 fractures or injuries among our studied population. Nevertheless, recent data have shown that over one year period
294 the incidence of injury in VBD was 1.42 per student and the risk of injury 76% [42]. Also, in PBD, a total of 355
295 injuries were recorded during a year, with an overall incidence of 6.8 injuries per dancer [43]. However, to our
296 knowledge, there are no available data on the association between dance injuries and low BMD [8]. Notwithstanding,
297 the prevalence of Z-scores below -1.0 is significantly higher among our dance population compared with controls.
298 Indeed, since athletes in weight-bearing sports usually have 5-15% higher BMD than non-athletes [4], the ACSM
299 emphasizes that a BMD Z-score of < -1.0 in athletic populations should be further investigated, even in the absence
300 of fractures [4]. However, to the best of our knowledge, there are no preventative/screening measures in dance
301 population regarding overall dancers' bone health yet.

302 It is reasonable to assume that the present study might have been influenced by methodological limitations
303 such as the use of a self-reported questionnaire to assess age at menarche, gynaecological age and Tanner stage. We
304 also acknowledge the lack of injury and fracture records for our participants as well as alcohol intake. Another
305 limitation may be that the current data incorporate dancers born and raised in north or south Europe, but performing
306 at the same company. We further recognise the potential selection bias of the current participants since they were
307 recruited from specific geographic regions. Finally, the assessment of bone geometry, a known determinant of bone
308 strength, should also be considered in future studies to further substantiate the findings of this study.
309

310

311 **CONCLUSIONS**

312 Compared to controls, female and male vocational ballet dancers demonstrated lower bone mineral density at impact
313 and non-impact sites; maturation markers in the young female vocational dancers seem to explain these findings only
314 at impact sites. In contrast, unlike male professional dancers who demonstrated a healthy bone mineral density
315 profile, their female counterparts revealed lower bone mass at the studied non-impact site compared to controls, but
316 higher values at impact sites. Future studies should explore how bone mass changes as vocational dancers grow and
317 progress to professional level.

318

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323

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325 George S. Metsios, Andreas D. Flouris, Nuno Adubeiro, Luísa Nogueira, and Lygeri Dimitriou declare that they
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327

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