Sports Med (2015) 45:257–268
DOI 10.1007/s40279-014-0268-5

SYSTEMATIC REVIEW

Prevalence of Low Bone Mineral Density in Female Dancers

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Published online: 4 October 2014

Abstract

Background and Objective While some authors report that dancers have reduced bone mineral density (BMD) and increased risk of osteoporosis, others have stressed the positive effects of dance training on developing healthy BMD. Given the existing controversy, the aim of this systematic review was to examine the best evidence-based information available in relation to female dancers.

Methods Four databases (Web of Science, PubMed, EBSCO, Scopus) and two dance science journals (*Journal of Dance Medicine* and *Science and Medical Problems of Performing Artists*) were searched for relevant material using the keywords “dance”, “ballet”, “BMD”, “bone density”, “osteoporosis” and “female athlete triad syndrome”. A total of 257 abstracts were screened using selected inclusion (studies involving bone measurements in dancers) and exclusion (editorials, opinion papers, chapters in books, narrative reviews and non-English language papers) criteria according to PRISMA guidelines. Following the above screening, a total of 108 abstracts were identified as potentially relevant. After the exclusion of conference proceedings, review papers, studies focusing only in male dancers and studies in which dancers’ information were combined with other athletes, the eligible papers were subsequently assessed using the GRADE system and grouped according to: (1) prevalence of low BMD and associated factors, (2) incidence of low BMD and risk factors, (3) prevention/treatment of low BMD in dancers, and (4) other studies.

Results Of the 257 abstracts that were initially screened, only 35 studies were finally considered. Only one of these 35 was of high quality, while the remaining 34 were of relatively low quality. Seven studies reported prevalence of low BMD and associated factors, 10 reported associated factors with no prevalence data, while one reported prevalence with no associated factors data. One study cited risk factors, while another one elaborated on the treatment of low BMD in dancers. The remaining 15 studies were classified as “other studies”.

Conclusions It remains unclear whether low BMD is prevalent in female dancers. The present review highlights the need for high-quality BMD research in this area.

Key Points

There is no universal agreement on whether female dancers demonstrate low bone mineral density

Dance medicine requires more high-quality research

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1 Introduction

Bone mineral density (BMD) is a parameter commonly used to assess bone health, including the diagnosis of osteoporosis and prediction of bone fracture risk [1, 2]. It is believed that the aetiology of low BMD is both genetic and environmental [3], with the former to explain up to 80 % of the variance, whereas the remaining 20 % is modulated by environmental factors such as diet and physical activity [4]. However, only environmental factors can be possibly modified by appropriate interventions with the aim to stimulate bone mass gains [5]. Indeed, it has been found that participation in various physical activities is associated with positive effects on bone mineral accrual [5–7]. Weight-bearing activities seem to be the most effective for bone mass increases [8, 9], which, nevertheless, seem to be site specific [10]; tennis players have greater BMD in their dominant arm (impact site) compared with their non-dominant arm [11].

Dance training regiments during adolescence have been linked with low body weight, late onset of menarche and menstrual dysfunctions [12] which, in turn, increase the risk of developing low BMD and osteoporosis in later life [13]. The American College of Sports Medicine (ACSM) [14] portrays low BMD as a constituent of the female athlete triad. According to the ACSM, the female triad is a syndrome that involves the presence of three components—low energy availability, menstrual disturbance and low BMD—that are often interrelated. Thus, the female triad is a spectrum of conditions that begins with energy or nutrient restriction, which may lead to the development of hypothalamic amenorrhea, with a subsequently negative impact on BMD. Participants in physical activities that emphasise an aesthetic build and low body weight have been identified as potentially at risk for developing the syndrome [14]. Given that dancing is an artistic expression in which physical fitness and aesthetics are key elements of performance [15], dancers might also fall into the same category. Indeed, observational data have suggested that intense dance training during the growing years, combined with low energy intake and low body weight, might cause menstrual dysfunctions which, subsequently, could negatively affect the skeletal system [16]. Keay and colleagues [17] revealed that amenorrheic dancers have low *Z*-scores at the lumbar spine compared with controls, but eumenorrheic dancers have high *Z*-scores at the femoral neck compared with the normal population. Other published data demonstrated that as high as 40 % of professional dancers could show symptoms of the triad [18]. Moreover, professional ballet dancers have been consistently found with low BMD [19–22]. All these authors agree that dancers are susceptible to menstrual disorders, and the weight-bearing exercise of dance training is unlikely to offset the harmful effects of amenorrhea/oligomenorrhea on BMD. The International Association of Dance Medicine and Science [23] published a statement highlighting BMD as a topic of major concern, associated with several health risks in dancers.

Contrary to the above, some authors advocate that professional dancers have higher BMD compared with controls, despite low body mass and late menarche [24]. Similarly, retired ballerinas [25] and adolescent dancers [26] were found not to be at risk of developing low BMD or osteoporosis. Consequently, the question of whether dancers are at risk of developing low BMD is unanswered. Therefore, the aim of the present literature review was to systematically investigate and examine the information available in relation to the prevalence and incidence of low BMD in female dancers.

2 Methods

2.1 Literature Search and Identification

A systematic search of literature was undertaken using four electronic databases (Web of Science, PubMed, EBSCO, and Scopus). The search was extended to two specific dance science publications (*Journal of Dance Medicine and Science* and *Medical Problems of Performing Artists*) to ensure that we considered all relevant data. Material from the year of their inception up to January 2014, was identified using the terms “dance” and “ballet” combined with “BMD”, “bone density”, “osteoporosis” and “female athlete triad syndrome”.

We included all studies involving bone measurement (at any site, with any type of device) in dancers (any type of dance and competency level). Because of the limited number of randomised controlled trials (RCTs), cross-sectional, non-randomised, longitudinal and retrospective cohort studies were also included. In contrast, editorials, conference proceedings, review papers, opinion papers, chapters in books, narrative papers and non-English language publications were excluded as they are generally considered to be of low-quality studies [27]. We also excluded studies that examined only male dancers because only two such papers were found. In contrast, studies that reported male and female data separately were included, but we only considered and analysed data on female dancers.

Papers on the prevalence of low BMD and associated factors, incidence of low BMD and risk factors, and treatment/prevention of low BMD were classified as “relevant material”. Papers with no such information were classified as “other studies”. This categorisation was assisted by two independent experts who appraised the relevance of each identified study. Prevalence and incidence were defined as the total number of existing cases with low BMD, and as the number of new cases with low BMD emerging during a specific period of time, respectively.

2.2 Article Quality Assessment

The quality of the eligible papers was assessed according to the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) system, an appropriate tool for assessing the quality of published reports [28]. RCTs were assessed based on six parameters: (i) risk of bias, (ii) indirectness, (iii) imprecision, (iv) publication of bias, (v) large effect and (vi) dose response. Non-RCTs were evaluated using the following three parameters: (i) large effect, (ii) dose response and (iii) all plausible residual confounding. GRADE classifies published material as high, moderate, low or very low quality, whereas RCTs start at a high-quality level and non-RCT studies at a low-quality level. Based on the information provided by the authors in each selected paper and applying GRADE's parameters, two experienced appraisers rated them as "high" or "low" (no point given), "low plus one" (one point given) and "low plus two" (two points given). We also considered the guidelines of the preferred reporting items for systematic reviews and meta-analyses (PRISMA) [29].

3 Results

Using the terms "dance" and "ballet" combined with "BMD", "bone density", "osteoporosis" and "female athlete triad syndrome", 2,785 outputs initially emerged. After titles and abstracts were screened, 108 articles were identified as potentially relevant and were retrieved as full texts. Following detailed examination, 73 of these articles were excluded, while only 35 fulfilled the set criteria (Fig. 1). The latter 35 articles consisted of 31 cross-sectional studies, one longitudinal study, one mixed-longitudinal study, one retrospective study and one RCT.

Of these 35 selected studies, 18 were identified as related to the prevalence of low BMD and associated factors, one to the incidence of low BMD and risk factors, one to treatment or prevention of low BMD, and 15 were classified as "other studies".

3.1 Description of the Selected Studies

The quality scores of the 35 selected studies appear in Table 1. Twenty out of the 35 publications received a "low" score, 11 had a score of "low plus one", three collected a "low plus two" and only one was considered to be high quality (RCT).

Figure 2 shows the general characteristics of the selected papers. Of the 35 studies, 16 studies examined professional female dancers (three of which dealt with retired dancers) and seven studies examined pre-professional dance students (age range, 16.4–20 years), while 12 studies examined non-professional dancers. Control groups were included in 27 studies.

Dual-energy X-ray absorptiometry was the most frequently used methodology to evaluate bone parameters (24 studies). Of these, 13 evaluated both dance specific impact and non-impact sites, 16 reported diet analysis via a 3-day record, 12 examined hormone levels (most hormones relating to the menstrual cycle) and three studies assessed energy expenditure of professional dancers.

The main outcomes of the 27 studies that compared dancers' bone mass with controls or normative values vary considerably with 15 of them revealing that dancers have low BMD at least in one site, eight studies suggest that dancers' BMD is equal to non-dancers and four studies disclosed that dancers have high BMD values (Fig. 3). However, it should be stressed that these outcomes come from published material classified as low quality based on the GRADE system.

3.2 Prevalence of Low BMD and Associated Factors in Female Dancers

Eight cross-sectional studies fulfilled the eligible criteria on the prevalence of low BMD (Table 1). All studies were on ballet dancers, whose experience and level of performance varied from pre-professional students to retired professional dancers. Variations were also found in terms of anatomical zones measured.

From the three studies that have examined professional female ballet dancers, one estimated the prevalence of low BMD at the lumbar spine to be 40 % [19], while another one estimated the same parameter to be 23 % [30]. The third study examined the presence of the female athlete triad syndrome in two professional ballet companies; it was found that 40 % of the dancers exhibited symptoms of the triad, resulting in low BMD at the total body [18].

One study involving retired professional female ballet dancers revealed a higher prevalence of osteoporosis at non-impact sites (26.7 vs. 15.8 %), the hip (6.9 vs. 3.9 %) and the femoral neck (17.8 vs. 16.8 %) compared with controls, but a lower prevalence of osteoporosis at the total body (8.9 vs. 9.9 %) and the lumbar spine (11.9 vs. 15.8 %) [25]. These authors also found that the prevalence of osteopenia in retired ballet dancers was 46.5 % (39.6 % for controls).

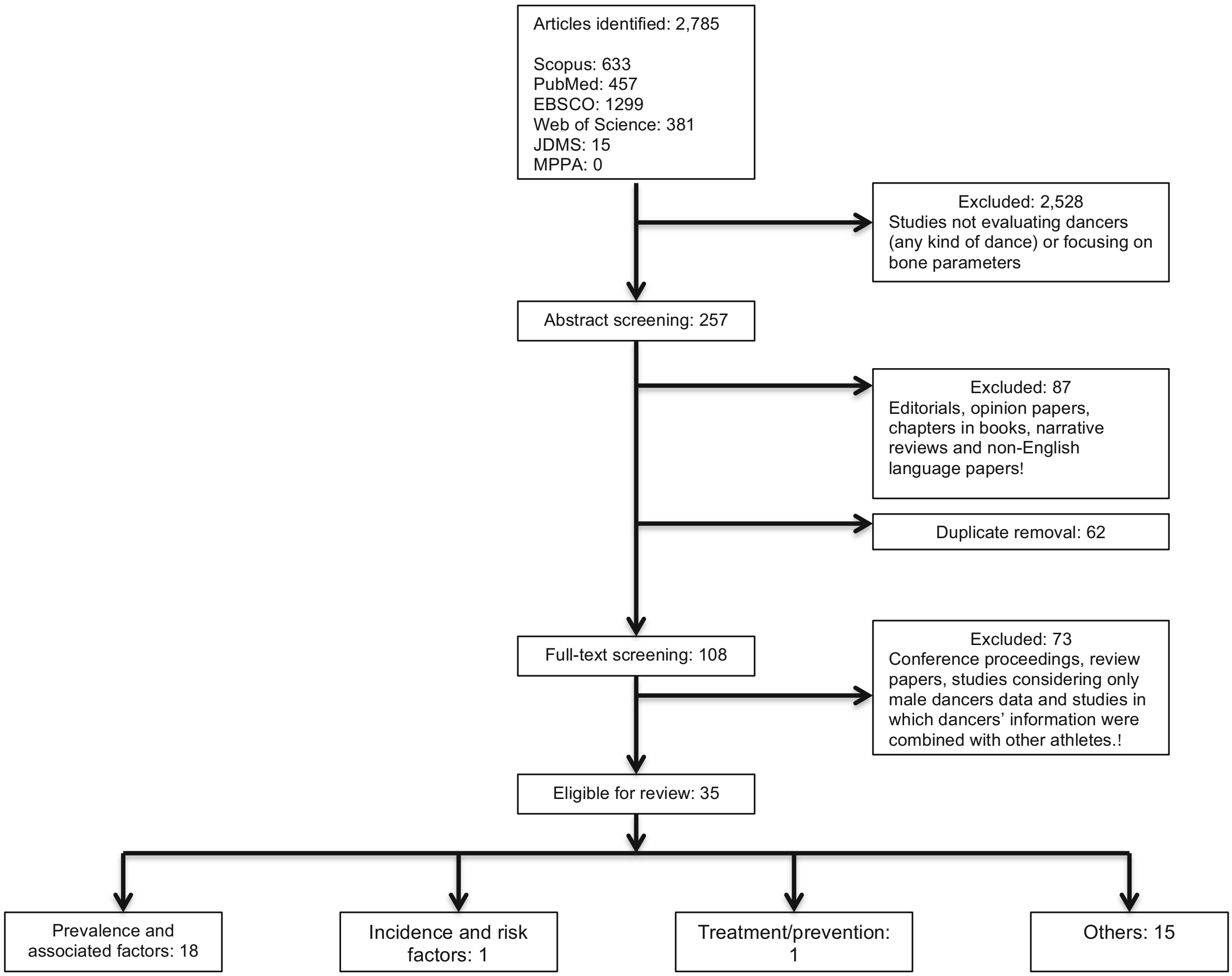

Fig. 1 Flow chart of the identified and selected studies. *JDMS Journal of Dance Medicine and Science*, *MPPA Medical Problems of Performing Artists*

Female dance students were investigated in some studies. Valentino and colleagues [16] reported that 60 % of dance students and 55 % of ex-dance students demonstrated a *Z*-score below 2.5 for the lumbar spine, while 30 and 22 % of dance and ex-dance students, respectively, exhibited a Z-score between one and two for the same site [according to the World Health Organization (WHO)] [30], osteoporosis is considered when the BMD value is at least −2.5 standard deviations (SD) below the mean for age, and osteopenia when BMD value is between −1.5 SD and −2.5 SD below the mean for age). Burckhardt and colleagues [22] estimated the prevalence of low BMD to be 37 % at the lumbar spine in Asian and Caucasian pre-professional female dance students, whereas Chinese female dance students had a significantly higher prevalence of osteopenia (26.7 %) compared with age-matched controls (14.3 %) [32]. Regarding total body BMD in female dance students, Yannakoulia and colleagues [33] found a prevalence of 37.8 %.

Table 2 summarises all studies that provide evidence regarding the prevalence of low BMD. It seems that dance students had higher prevalence than their professional counterparts for the same sites. The average values for dance students and professional dancers were: 47.7 vs. 25.9 % at the lumbar spine, and 32.9 vs. 29.6 % at the total body. In professional female dancers, the highest prevalence is at non-impact sites (40 %), followed by the total body (29.6 %) and the lumbar spine (25.9 %). Compared with controls, both dance students and professional dancers had a higher prevalence of low total body BMD. However, the prevalence of low BMD is lower in retired dancers at the lumbar spine and total body when compared with control populations of the same age.

Of all studies examining the prevalence of low BMD in dancers, seven reported certain associated factors (Table 1). This included taking oral contraceptives (those taking contraceptives had particularly low BMD) [19],

Table 1 Studies included in the systematic review and their main findings

Group	Article	Participants	Main findings[a]	Quality
Prevalence and associated factors	Armann et al. [19] (1990)	Female prof ($n = 5$, 26 ± 4.6 years); controls ($n = 6$, 16.2 + 1.2 years)	Prevalence: dancers aged over 20 years (spine): 40 %; dancers aged over 20 years (radius): 40 % Associated factors: taking oral contraceptives	Low
	Warren et al. [20] (1991)	Female prof ($n = 51$, 13–29 years); controls ($n = 47$, 13–29 years)	Prevalence: unknown Associated factors: menstrual disturbances	Low (plus one)
	Karlsson et al. [34] (1992)	Female ($n = 25$, 19–68 years); controls ($n = 42$, age matched)	Prevalence: unknown Associated factors: menstrual disturbances	Low (plus one)
	Bass et al. [35] (1994)	Female prof ($n = 32$); controls ($n = 23$, age matched)	Prevalence: unknown Associated factors: menstrual disturbances	Low
	Young et al. [39] (1994)	Female vocational ($n = 44$, 17 ± 0.2 years); sedentary amenorrheic ($n = 18$, 18.1 ± 0.4 years); normal menstrual ($n = 23$, 16.7 ± 0.3 years)	Prevalence: unknown Associated factors: low body weight	Low (plus one)
	Lichtenbelt et al. [24] (1995)	Female prof ($n = 24$, 22.6 ± 4.5 years)	Prevalence: unknown Associated factors: age at menarche	Low
	Khan et al. [25] (1996)	Retired prof female ($n = 101$, 51.1 ± 1.4 years); controls ($n = 101$, age matched)	Prevalence: osteoporosis: TB, 8.9 % dancers vs. 9.9 % controls, with the corresponding values as follows: radius 26.7 vs. 15.8 %, hip 6.9 vs. 3.9 %, FN 17.8% vs. 16.8 %, intertrochanteric and trochanter 16.8 vs. 14.8%, LS 11.9 vs 15.8 %, any site 23.8 vs. 38.6 %; osteopenia: any site, 46.5 % vs. 39.6 % Associated factors: menstrual disturbances	Low (plus two)
	Pearce et al. [21] (1996)	Female vocational students ($n = 41$, 17.2 ± 0.2 years); controls ($n = 46$, 17.5 ± 0.2 years)	Prevalence: unknown Associated factors: menstrual disturbances	Low (plus one)
	Keay et al. [17] (1997)	Retired prof female ($n = 57$, 25–50 years)	Prevalence: unknown Associated factors: age at menarche; menstrual disturbances	Low (plus two)
	Valentino et al. [16] (2001)	Female vocational students ($n = 48$, 21.5 ± 3.7 years); ex-students ($n = 50$, 22.3 ± 1.8 years); controls ($n = 76$, 22.5 ± 1.5 years)	Prevalence: 60 % of the dancers and 55.6 % of ex-dancers had a *Z*-score below 2.5 at LS; 30 % of dancers and 22.2 % of ex-dancers had a *Z*-score between 1 and 2; controls: unknown Associated factors: unknown	Low
	Kaufman et al. [37] (2002)	Female prof ($n = 21$, 23.2 ± 2.8 years); controls ($n = 27$, 24.5 ± 2.6 years)	Prevalence: unknown Associated factors: rest metabolic rate; low energy intake	Low
	Quintas et al. [38] (2003)	Female ($n = 33$; 16.2 ± 2.0 years); controls ($n = 90$, 16.7 ± 1.0 years)	Prevalence: unknown Associated factors: low body weight; low energy intake	Low
	Yannakoulia et al. [33] (2004)	Female vocational students ($n = 37$, 20.7 ± 1.8 years)	Prevalence: 37.8 % of dancers had lower total BMD Associated factors: menstrual disturbances	Low (plus one)
	To et al. [36] (2005)	Female vocational students ($n = 35$, 17–19 years); controls ($n = 35$, 17–19 years)	Prevalence: unknown Associated factors: menstrual disturbances	Low
	Yang et al. [32] (2010)	Female adolescent ($n = 60$, 16.5 ± 0.7 years); controls ($n = 77$, 16.4 ± 0.6 years)	Prevalence: 26.7 % of dancers found as having osteopenia compared with 14.3 % for controls Associated factors: menstrual disturbances; age at menarche	Low
	Dolyle-Lucas et al. [18] (2010)	Female prof ($n = 15$, 24.2 ± 1.3 years); controls ($n = 24$, 23.7 ± 0.9 years)	Prevalence: 40 % of dancers exhibited symptoms of the three conditions comprising the female athlete triad; controls: 0 % Associated factors: menstrual disturbances	Low (plus one)
	Hoch et al. [30] (2011)	Female prof ($n = 22$, 23.2 ± 4.7 years)	Prevalence: 23 % had low BMD in one or more sites; 23% had low BMD at LS and 9% at TB; *Z*-score <-2 was not met by any of dancers Associated factors: low brachial artery flow-mediated dilation	Low
	Burckhardt et al. [22] (2011)	Female vocational students ($n = 127$, 16.7 ± 0.8 years)	Prevalence: 37 % of dancers had LS BMAD below the fifth percentile Associated factors: non-dietary protein intake	Low (plus one)

Table 1 continued

Group	Article	Participants	Main findings[a]	Quality
Incidence and risk factors	Warren et al. [40] (2002)	2-year follow-up Female prof and students from regional and national schools ($n = 54$); controls ($n = 44$) (22.4 ± 4.6 years)	Incidence: unknown Risk factors: menstrual disturbances	Low
Treatment/ prevention	Warren et al. [41] (2003)	2-year follow-up. Amenorrheic ($n = 24$) and eumenorrheic dancers ($n = 31$) from regional schools and companies (22.0 ± 4.6 years)	Intervention: amenorrheic dancers receive placebo or Premarin, 0.625 mg for 25 days monthly, with Provera, 10 mg, for 10 of these 25 days (hormone therapy) for 2 years Outcomes: No difference in BMD between treated or placebo group	High
Other studies	Wolman et al. [42] (1991)	Female prof ($n = 10$, 20.7–25 years); runners; rowers; controls ($n = 13$, 26.5–30.3 years)	Prevalence: unknown Associated factors: unknown Dancers had similar BMD values compared with controls	Low
	Frederick et al. [43] (1992)	College dancers ($n = 14$, 17–25 years); postmenopausal women; track team; controls ($n = 14$, 17–25 years)	Prevalence/associated factors: unknown No significant differences in BMD among the four groups	Low
	Foldes et al. [49] (1997)	Female high-school dance students ($n = 27$, 15.6 ± 1.2 years); controls ($n = 27$, 15.6 ± 0.8 years)	Prevalence: unknown Associated factors: unknown BMD did not differ between groups	Low (plus one)
	Cuesta et al. [48] (1996)	Female ($n = 15$, 25.1 ± 3.8 years); controls sex and age matched	Prevalence: unknown Associated factors: unknown BMC low in arms when compared with controls (both female and male)	Low
	Khan et al. [76] (1998)	Retired female prof ($n = 101$, 51.4 ± 14.3 years); controls ($n = 99$, $n = 51.5$ ± 16.0 years)	Prevalence: unknown Associated factors: unknown Hours of ballet training per week during infancy was positively associated with BMD	Low (plus two)
	Bennel et al. [51] (2000)	Non-elite female students ($n = 78$, 9.6 ± 0.8 years); controls ($n = 63$, 9.6 ± 0.8 years)	Prevalence: unknown Associated factors: unknown BMC upper limb lower in dancers; BMD high in dancers at FN, hip; no differences at LS	Low
	Tsai et al. [50] (2001)	Female ($n = 29$, 16.3 ± 0.5 years); controls ($n = 20$, 16.6 ± 0.8 years)	Prevalence: unknown Associated factors: unknown Similar BMD at LS and FN between groups	Low
	Munoz et al. [44] (2004)	Female dancers ($n = 12$, 16.2 ± 2.0 years); rhythmic gymnasts; controls ($n = 14$, 16.9 ± 1.0 years)	Prevalence: unknown Associated factors: unknown BMD at LS normal in all groups; significant decrease found in dancers and gymnasts at forearm compared with controls	Low
	Matthews et al. [52] (2006)	Non-elite dancers ($n = 82$, 8–11 years); controls ($n = 61$, 8–11 years)	Prevalence: unknown Associated factors: unknown Dancing is associated with a positive effect on bone mass	Low (plus one)
	Oral et al. [54] (2006)	Female ($n = 26$); controls: age and sex matched ($n = 100$)	Prevalence: unknown Associated factors: unknown Dancers had significant higher calcaneal QUS measurements compared to controls	Low (plus one)
	Kilicarslan et al. [47] (2007)	Female dancers ($n = 22$, 29.8 ± 3.0 years); controls ($n = 20$, 28.6 ± 2.6 years)	Prevalence: unknown Associated factors: unknown *Z*-scores at the LS and FN significantly greater in dancers; no significant difference in *Z*-scores at the forearm	Low

Table 1 continued

Group	Article	Participants	Main findings[a]	Quality
	Yang et al. [52] (2009)	Female adolescent ($n = 60$, 16.5 ± 0.7 years); controls ($n = 77$, 16.4 ± 0.6 years	Prevalence: unknown Associated factors: unknown Plasma leptin levels is not a direct determinant of BMD	Low
	Hinrichs et al. [45] (2010)	Female dancers ($n = 13$); runners; team athletes; triathletes; combat players; controls ($n = 61$)	Prevalence: unknown Associated factors: unknown BMD at LS was the lowest in dancers	Low
	Friesen et al. [46] (2011)	Female dancers from university ($n = 32$, 22.1 ± 1.4 years); controls ($n = 30$, 21.4 ± 1.5 years)	Prevalence: unknown Associated factors: unknown BMD did not differ between groups; BMD at LS and hip higher in dancers	Low
	To et al. [26] (2011)	Vocational female students ($n = 47$, 17–20 years); controls ($n = 36$, 17–20 years)	Prevalence: unknown Associated factors: unknown Dancers do not exhibit low BMD at any site	Low (plus one)

Prof professional, *BMD* bone mineral density, *BMC* bone mineral content, *BMAD* bone mineral apparent density, *QUS* quantitative ultrasound, *LS* lumbar spine, *FN* femoral neck, *TB* total body

Values are mean ± standard deviation or range except where stated otherwise

[a] Prevalence/incidence = prevalence/ incidence of low BMD

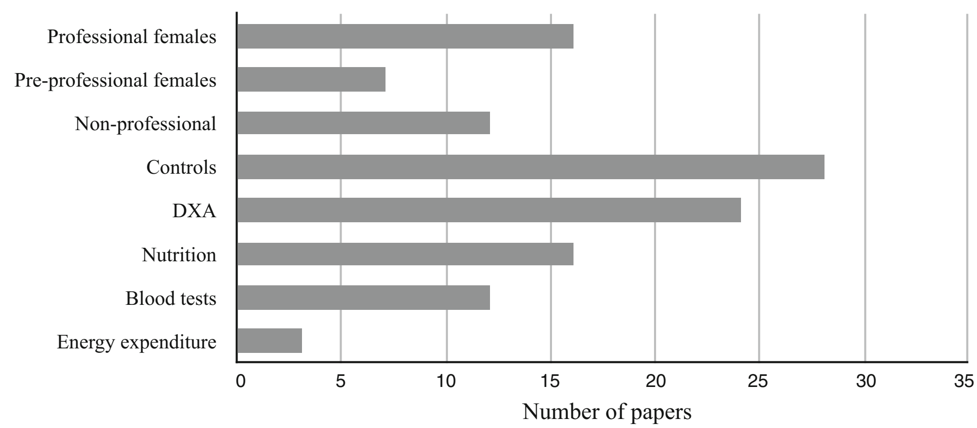

Fig. 2 General characteristics of the selected papers. *DXA* dual-energy X-ray absorptiometry

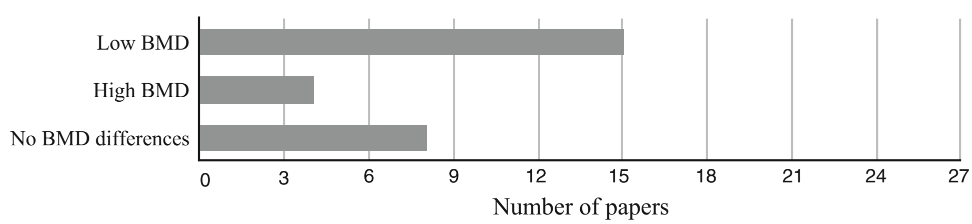

Fig. 3 Main outcomes of the 27 studies that compared dancers' bone mass with controls or normative values. *BMD* bone mineral density

Table 2 Prevalence estimates for low bone mineral density in female dancers (data manually calculated by the present authors from all published papers included in the "prevalence and associated factors" group)

	Prevalence (%)					
	Pre-professional		Professional		Retired professional	
	Dancers	Controls	Dancers	Controls	Dancers	Controls
Femoral neck	No published data	No published data	No published data	No published data	17.8	16.8
Lumbar spine	47.7	No published data	25.9	No published data	11.9	15.8
Non-impact sites	No published data	No published data	40	No published data	26.7	15.8
Total body	32.9	14.3	29.6	0	8.9	9.9

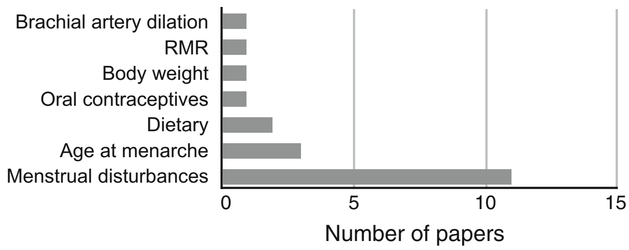

Fig. 4 Factors associated with low bone mineral density reported in the selected studies. *RMR* resting metabolic rate

menstrual disturbances [18, 25, 26, 33], decreased brachial artery flow-mediated dilation [30], age at menarche [32] and dietary deficiencies [22]. Table 1 also depicts 10 cross-sectional studies that, although providing no information regarding prevalence, dealt with factors associated with low BMD in dancers. These factors included menstrual disturbances [20, 21, 34–36], dietary deficiencies [37, 38], age at menarche [17, 24], decreased body weight [39] and decreased resting metabolic rate [37]. Figure 4 summarises these associated factors. It becomes clear that the most quoted factor for low BMD is menstrual disturbances. However, only seven studies used multivariate analyses to adjust for potential covariates [20, 22, 25, 32–34, 39], therefore these associated factors constitute only preliminary evidence, as most of the relevant studies were observational in nature and used small sample sizes.

3.3 Incidence of Low BMD and Associated Risk Factors in Female Dancers

We found no data on the incidence of low BMD in dancers. However, one study did provide information on potential risk factors (Table 1), demonstrating that female professional ballet dancers and dance students with amenorrhea had low BMD at the lumbar spine compared with eumenorrheic dancers. These authors also reported that dancers who resumed menses significantly increased BMD at the wrist and lumbar spine (17 %), but could not achieve normal levels. Nonetheless, this was classified as a low-quality study owing to the small sample size and low-level statistical analyses.

3.4 Treatment or Prevention of Low BMD in Female Dancers

Only one study received a high-quality rating in this area (Table 1). This study adopted a placebo-controlled randomised design to investigate the ability of oestrogen therapy to stimulate normalisation of bone mass in amenorrheic dancers [41]. Results indicated no significant difference between the treatment and placebo groups.

3.5 Other Studies

Although these 15 studies provided no direct information on prevalence/associated factors, incidence/risks factors or treatment of low BMD in dancers, they could be useful as they included measurements of dancers' bone mass (Table 1). These were all low-quality studies, and most of them included other populations besides dancers [42–46]. Interestingly, published data obtained exclusively from dancers demonstrated conflicting results. Some indicated that bone mass of professional dancers and full-time dance students was significantly higher than controls [26, 47], another did not [48], while some data disclosed similar values for dancers and non-dancers [49, 50]. Table 1 also includes two studies, a cross-sectional [51] and a longitudinal [52], that have showed the positive effects of dance on bone using non-elite dance students. A cross-sectional study revealed that plasma leptin levels in adolescent female dancers are significantly lower in comparison to female controls; however, it is not a direct determinant of BMD in adolescent dancers [53]. Last, a study using quantitative ultrasound found that BMD measurements were significantly higher in dancers than in controls [54].

4 Discussion

Unlike athletic populations [55–57], there has been no published information on the short- or long-term health consequences of low BMD in dancers. Therefore, the aim of the current review was to systematically examine the available information regarding the prevalence of low BMD in dancers.

To our knowledge, this is the first systematic review on dancers' BMD. We found that the reported data are ambiguous and limited to principally observational studies of average to low quality. Specifically, only eight of the 35 finally selected studies dealt with the prevalence of low BMD in dancers, 17 on associated factors, one on risk factors, one on treatment and none reported on the incidence of low BMD. The majority of the studies have focused on the assessment of professional female ballet dancers, and only three published reports provide prevalence estimates for control populations [18, 25, 32]. Therefore, it is difficult to draw firm conclusions as to whether dancers have higher or lower BMD prevalence compared with the general population because there is no published information on the prevalence of low BMD in control populations at the femoral neck, lumbar spine and non-impact sites in both students and professional dancers. In addition, data shown in Table 2 regarding prevalence estimates for student controls at the total body were provided by a single study [18]. Similarly, all prevalence estimates for retired professional dancers (and respective controls) shown in Table 2 also came from a single study [25], as well as prevalence estimates for professional controls [32]. Therefore, there is a need to confirm these values in future high-quality and well-designed research studies.

At least one study, using quantitative computed tomography, showed that 60 % of dance students and 55 % of ex-dance students demonstrated a *Z*-score below 2.5 for the lumbar spine, and 30 and 22 % of dance and ex-dance students exhibited a *Z*-score between one and two for the same site [16]. However, it is worth noting that these authors used the WHO criteria to diagnose osteoporosis/osteopenia, which are only suitable for dual-energy X-ray absorptiometry measurements, not for quantitative computed tomography [59]. Furthermore, WHO criteria were designed for postmenopausal women, not for young and active individuals. Thus, the ACSM suggests adherence to guidelines from the International Society of Clinical Densitometry instead of guidelines from the WHO when considering athletic populations [14].

We also noticed that there is no information on the prevalence of low BMD in dance vocational students at non-impact sites and the femoral neck (impact site). However, given the nature of dance training and the importance of the growing years for bone mass development [59, 60], it could be sensible for future studies to assess impact and non-impact sites in vocational dance students. Further, there are no studies reporting incidence estimates of low BMD in dancers. To address this issue, longitudinal designs are needed; 31 of the 35 finally selected studies for the current review adopted cross-sectional designs.

Most of the studies included in this review reported menstrual disturbances as an associated factor and one study as a risk factor. However, these associations should be treated with caution given that all studies used a small sample size, and the majority of them did not apply multivariable analyses to adjust for potential covariates and were, therefore, classified as low quality based on the GRADE system. Moreover, research involving associated factors has been limited by the fact that they restrict analyses mainly to menstrual disturbances and nutrition. There are other factors that may potentially play a significant role on bone metabolism, such as bone mass-related hormones [61]. Future studies should incorporate possible associated and risk factors within a multivariate design.

There have also been limited investigations on the effectiveness of different interventions within a RCT design; only one study used such a design [41]. Therefore, current findings on this issue can only be treated as preliminary evidence that needs to be confirmed in appropriately designed studies.

Of particular interest is that some of the existing literature on dancers' BMD suggests that bone mass may not accumulate in the same manner in adolescents as in mature individuals, because a delay in menarche may affect bone mass gains [20]. To date, there is no evidence supporting this claim as only one study followed dance students in a mixed longitudinal design [52]. However, these authors examined female non-elite dancers and, therefore, their findings are not transferable to elite vocational dance school populations given the differences in selection criteria, training load and dietary regimes.

The conflicting results found herein (i.e. studies showing lower BMD in dancers and others showing higher BMD) could be due to differences in dancers' performance levels, study design and methodologies employed. Dual-energy X-ray absorptiometry has been the most used device adopted by the studies of this review, confirming that it is the best current test to determine bone mass [62]. However, the anatomical sites measured and the sample characteristics of these studies differ, a fact that might have implications on BMD outcomes. BMD might be quite diverse in subjects with different training levels [63], ages [64] and ethnicities [65, 66]. Indeed, ageing itself is considered to be a risk factor for low BMD and osteoporosis [67]. While childhood and adolescence are crucial periods for bone mass gains, adulthood is considered to be a bone-mass-maintenance period; during older adulthood, rapid bone loss can occur [68]. It is expected, therefore, that the prevalence of low BMD in dancers will change according to growth stage and age. Nonetheless, none of the included studies reported a prevalence of low BMD in dancers according to age. In fact, only three studies of the "prevalence and associated factors" group considered age cluster—adolescence [22, 32] and older adulthood [25]. The remaining studies of this group have included a wide range of ages, and dancers on different growth stages were considered in the same age group. For better information on dancers' BMD and associated factors, future studies should be more focused on the age range.

Although scientific research has not established with certainty the intensity, frequency and volume of exercise that will increase BMD in the general population and athletes, published reports suggest that as few as 2–3 training days per week of combined weight-bearing exercises with high-impact exercises (e.g. jumping) are sufficient to stimulate bone metabolism [5]. In general, dancers are involved in daily classes and several hours of rehearsing [69] of medium physical demands [70], whereas muscular strength and jumping play a key role for performance [71]. However, although dancing has been hailed as an osteogenic activity [25], we found no studies reporting on the thresholds (intensity, frequency, volume) above which dancing might stimulate bone mass gains.

Furthermore, none of the included studies refer to the possible relationships between dance training loadings (intensity, frequency, volume), menstrual disturbances and bone mass acquisition. In contrast, it has been suggested that professional dancers are exposed to a high risk of injury [72–75], but interestingly no studies have been identified for reporting a possible association between low BMD and dance injuries. Finally, there are no available data on the incidence of low BMD in dancers. Therefore, trends over time cannot be analysed and risk factors cannot be clearly determined.

4.1 Limitations

The main limitations in this study are related to the very topic of the current systematic review. The number of studies included herein was low both in numbers and quality. Moreover, the fact that the studies in question used different assessment sites, methodologies, type of dance and dancers' competency levels made it difficult to compare results and to draw firm conclusions.

5 Conclusions

The published work, which has been included in the present systematic review, cannot answer the fundamental question as to whether there is a high prevalence and incidence of low BMD in female dancers. Future research needs to focus on high-quality research designs that allow associated and risk factors to be examined within a controlled environment. Future research should also distinguish between dancers' training levels, ages and ethnicity.

Acknowledgements The authors would like to thank the Portuguese Foundation for Science and Technology for granting this research (SFRH/BD/88585/2012). The authors have no potential conflicts of interest that are directly relevant to the content of this review.

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