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Bone health in female ballet dancers: a review

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Abstract
Classical ballet is a physical art form with strict aesthetic requirements. A review of the contemporary literature shows that the desire to obtain a slender athletic physique, which is often required for success at the elite level, may place dancers at risk for the female athlete triad. Ballet training can be intense from a young age, and this may negatively impact the onset of puberty and associated gains in bone density. Ballet training may also play a role in developing menstrual dysfunction and amenorrhea, both of which are detrimental to bone density development during adolescence. However, classical ballet could provide a positive influence on bone growth due to the loads placed on the skeletal system in the training. Furthermore, strength and power training may improve bone health in ballet dancers of various levels of experience. This review examines the primary factors that may impact bone health in female ballet dancers.

Keywords: bone density, dance, female athlete triad, strength

Introduction

Classical ballet is a 300 year old artform that requires elegance, grace, artistry and athleticism. It takes many years of training to achieve the technical proficiency needed for a ballet career, together with the development of strength, power, coordination, cardiovascular fitness, and flexibility. Children often start ballet training in their primary school years or earlier, and vocational elite pre-professional training usually starts in early adolescence. The typical age for a female ballet dancer to enter the professional ranks is 18-20 years.

The female physique that is now required for a career in classical ballet is slender and lean, yet with muscle definition, so aspiring female ballet students, and those within the profession, aim to attain and maintain this body shape. The training and profession of classical ballet is extremely rigorous and competitive, similar to a fulltime elite athlete. This combination of heavy physical training and the need to have a lean physique, has led to the acknowledgement that the female athlete triad, a spectrum of related factors of low energy availability (with or without eating disorders), functional hypothalamic amenorrhoea, and osteoporosis (Nattiv et al., 2007), exists within classical ballet (Raastad et al., 2005, Doyle-Lucas et al., 2010).

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Classical ballet training involves high impact activities such as jumping, which load the skeletal system. Wolff's law explains that bone structure responds to the rate of mechanical strain placed upon the bone, with increases in bone tissue deposition occurring as a response to physical activity (Ruff et al., 2006). Therefore, ballistic movements in ballet training could have a positive effect on bone density development through childhood and adolescence (van Marken Lichtenbelt et al., 1995), assisting in the prevention of osteoporosis and injuries associated with low bone density such as stress fractures in female dancers. It is possible that if there is an osteogenic effect from ballet training, then ballet training could offset the negative impact on bone density caused by the female athlete triad.

In addition to external loading, bone mineral accrualis influenced by several factors including genetics, physical activity, and hormones (Soyka et al., 2000). Bone density increases during childhood and adolescence, with peak bone mass attained by late adolescence or early adulthood (Taaffe et al., 1997). Bone density increases rapidlyin females between 11-14 years of age and/or two years following menarche, then plateaus after approximately 16 years of age (Mallinson and De Souza, 2014, Taaffe et al., 1997, Soyka et al., 2000). If menarche is delayed or disrupted, the postponement of this important period of bone density development may result in lower levels of bone density in adulthood (Miller, 1999).Therefore, the purpose of this review is to examine the effects of ballet training on bone health in female ballet dancers. Specifically, this review will elucidate:

1. Thebone density levels of female ballet dancers
2. The effect of delayed menarche and amenorrhea on bone density in female ballet dancers
3. The effect ofparticipation in ballet training in childhood and adolescence on bone density development

Methods

A search of the scientific literature from the early 1990s to present day was performed by searching Pubmed and Google Scholar using the following keywords: bone density, bone mineral density, bone, female athlete triad, ballet, dance, menstrual dysfunction, ballet training, dance training, adolescent, childhood, and stress fractures. The original literature search included both male and female dancers, but was narrowedto only females, enabling the authorsto focus on particular components of the female athlete triad and ballet dancers, specifically, and menstrual dysfunction and bone density. Specific inclusion criteria included: 1) female child or adolescent ballet students, or 2) female adult professional ballet dancers. Studies that were not specific to classical ballet were excluded (i.e. collegiate dance). Due to the complexity of the female athlete triad, studies that specifically investigated other factors involved in the triad such as vitamin Dor hormonal influences or, researched bone density measurement techniques for dancers other than dual-energy X-ray absorptiometry (DXA), were excluded. Studies that examined general injuries in dance or had only male subjects were also excluded.

Results

Only full text articles were used in this review, sourced through Pubmed, Google Scholar, and a university's electronic library. Additionally, the reference lists of articles were also used to find relevant research. Sixteen original research publications, three reviews and one meta-analysis were included in this literature review. Articles will be discussed in detail throughout the remainder of this review, but have been summarized in Tables II and III.

Discussion

1) *The BoneDensity Levels in Female Ballet Dancers*

The selected studies investigating bone density in ballet dancers were cross sectional in design, with the exception of three longitudinal studies (Donoso et al., 2010, Matthews et al., 2006, Warren et al., 2002). A combination of medical assessments, interviews, dietary questionnaires, and bone density measurements was used. Subjects' results were compared against a control group (Cuesta et al., 1996, Doyle-Lucas et al., 2010, Kaufman et al., 2002, Khan et al., 1996, Valentino et al., 2001, Matthews et al., 2006, Munoz MT, 2004, Donoso et al., 2010) or in relation to criteria from the American College of Sports Medicine/World Health Organisation (Hoch et al., 2011). Two studies that did not include a control group compared their data to German and Italian reference population data supplied by the DXA manufacturer (van Marken Lichtenbelt et al., 1995, Yannakoulia et al., 2004), and, a third study without a control group compared their data to reference data for children aged 6-17 years from the United Kingdom and from the United States of America for girls aged 15-18 years (Burckhardt et al., 2011). One study used neither a control group nor reference data, but compared the results to other published research (Keay et al., 1997). A summary of these manuscripts is outlined in Table I.

1.1) Adult Dancers and Ex-Dancers

To determine the long term effect of ballet training on bone density, the incidence of osteopenia and osteoporosis was examined in retired professional and elite dancers who had osteoporosis risk factors such as menstrual disorders, caffeine and alcohol consumption, cigarette smoking, and suboptimal calcium and Vitamin D intake (Khan et al., 1996). These authors found no difference between the proportions of retired dancers and non-athletic controls who met the criteria for osteoporosis, as defined by the World Health Organisation as a t-score <2.5, despite the dancers' past history of multiple risk factors. In this case, it appears as though elite ballet training, even in the presence of risk factors for osteopenia or osteoporosis, did not hinder the women's ability to develop and sustain bone density over time when compared to non-dancers.

Two studies comparing ballet dancers to the age and weight matched reference data (provided by the dual energy x-ray bone densitometer (DXA) manufacturers in Germany (van Marken Lichtenbelt et al., 1995) and Italy (Yannakoulia et al., 2004)) report greater levels of bone mineral density in dancers than in the reference population. Specifically, professional ballet dancers had up to 9% greatertotal bone mineral density than the Italian Total Body White Reference Population data (Yannakoulia et al., 2004). In another study, professional ballet dancers had significantly greater total bone mineral density than age-and weight-matched German Spine and Total Body White Reference Population data (95%CI>100%), attributed to higher bone mineral density of the pelvis and legs (van Marken Lichtenbelt et al., 1995). Yannakoulia et al (Yannakoulia et al., 2004) reported that the elite ballet dancers had an average 16% greater leg bone mineral density compared to the Italian reference population data. This data shows site-specific effects that ballet has on the skeletal system.

Although ballet training seems to positively affect bone density in the pelvis and legs (Yannakoulia et al., 2004, van Marken Lichtenbelt et al., 1995), bone density of the spine has been shown to besignificantly lower ($p < 0.05$) by up to 8% in dancers,compared to age-matched non-athletic control groups(Cuesta et al., 1996, Valentino et al., 2001, Khan et al., 1996). Other authors, (Doyle-Lucas et al., 2010) reported no significant difference in bone density levels between university students used as controls and professional ballet dancers, although dancers with menstrual dysfunction had lower levels of bone density in the lumbar spine. Another study showed that bone mineral content of the arm was significantly lower ($p<0.05$) in dancersthan a control group (Cuesta et al., 1996)and lower bone density in the arm amongst ballet dancers has been reported to be up to 10% less than age-matched non-athletic controls (Khan et al., 1996). However, other research found professional ballet dancers and non-dancer controls to have similar levels of total body bone mineral content, andarm, spine, and leg regional bone mineral density (Kaufman et al., 2002). Khan et al. reported that retired professional ballet dancers had similar bone mineral density levels of the hip compared to age-matched controls, even with the presence of osteopenia and osteoporosis risk factors (Khan et al., 1996). These results are comparable to a recent study by Hoch et al (Hoch et al., 2011), who determined the prevalence of the female athlete triad in current professional female ballet dancers. The bone mineral density measurements of the dancers were compared to the American College of Sports Medicine / World Health Organisation's criteria for low bone density (Z Score <-1.0), and, whilst 77% of the dancers had low or negative energy availability and 36% had current menstrual dysfunction, none of the dancers had low bone density in the femoral neck or trochanter of the left hip. However, 23% of the dancers had low bone density in the lumbar spine, and 9% had low bone mineral density of the total body and the lumbar spine (Hoch et al., 2011). Collectively, these studies show that ballet training has an osteogenic effect on weight-bearing sites of the skeleton, most notably, the hip.

In summary, research indicates that bone density of the lumbar spine and arm in female adult ballet dancers may be less than the non-dancer, non-athletic population, yet the bone density of the hip may be similar. It is important, however, to place these research findings in the context of menstrual dysfunction and energy availability. Bone health is the downstream result of energy availability and menstrual function in females(Mallinson and De Souza, 2014). Thus, the relationship of the first two components of the athletic triad and their impact on dancers' bone density will briefly be discussed in a later section.

1.2) Child and Adolescent Dancers

Studies in child and adolescent populations reveal similar trends as adults for bone density levels in ballet students. However, as opposed to bone mineral density, some authors measured bone mineral content, as it is a more accurate measure of bone density of the growing skeleton (Matthews et al., 2006). Burkhardt et al (Burckhardt et al., 2011) measured bone mineral content of the left femoral neck and lumbar spine in 127 15-18year old pre-professional ballet students during an elite international ballet competition.They calculated bone mineral content (BMC), bone mineral content adjusted for height, and bone mineral apparent density (BMAD), the latter representing differences in the third dimension that is captured by bone mineral density. Reference data from the United Kingdom for girls aged 6-17 years was used as comparison for the lumbar spine, and reference data from the United States of America for girls aged 15-18 years was used for the femoral neck. The results showed that the ballet students had lower bone mineral contentof the spine, as the mean BMAD of the lumbar spine was 37%below the 5th percentile. However, the ballet dancers had significantly greater ($p<0.01$) average BMAD of the femoral neck compared to the mean value of the reference population. Therefore, it is evident that ballet dancing may result in preferable bone health at weight-bearing sites in child and adolescent ballet dancers. Site-specific effects of dance-induced mechanical loading across puberty in young girls were documented in a three-year longitudinal study comparing non-elite dancers and normally active, non-dancing 8-11 year old controls (Matthews et al., 2006). The dancers had significantly greater ($p<0.05$) lower limb, femoral neck, lumbar spine, and total bone mineral content than the controls, when body size, body composition, and biological age were controlled. These differences were noted one year after peak height velocity; however, femoral neck bone mineral content demonstrated a different pattern between the dancers and control group. The dancers had 4.0% more femoral neck bone mineral content at their peak height velocity compared to controls of same height, weight, and menarcheal status; additionally, these greater levels were seen at each bi-yearly measurement throughout the three year study period. The authors concluded that the greater femoral neck bone mineral content in the dancers was due to participation in dance training prior to puberty. One limitation of this study in the context of this paper is that the 8-11 year old girls participated in a variety of dance styles as well as classical ballet. Thus the specific effects of classical ballet as an osteogenic stimulus were not distinguished from other types of dance training. Finally, the control group had 4.5% more upper limb bone mineral content than the dancers, again highlighting site-specific effects of bone loading on the skeleton. This finding is in agreement with Munoz et al. (Munoz MT, 2004), who also found that adolescent dancers had significantly ($p<0.05$) lower bone mineral content in their arms, when compared to rhythmic gymnasts and non-athletic age-matched controls.

One meta-analysis has been conducted on bone density in dancers(Hincapie and Cassidy, 2010). The aim was to examine the literature on disordered eating, menstrual disturbance, and low bone mineral density. They accepted 23 out of a possible 124 articles for review, which consisted of 19 original research publications (13 cross sectional studies and 6 cohort studies), including both young and adult dancers. They reported prevalence estimates (at 95% confidence interval) of low bone density and osteoporosis in dancers as 10% for any site for young professional dancers, less than 50% for osteopenia for retired dancers (40% for controls), above 20% for osteoporosis at any site for retired dancers (40% controls), and similar levels of about 10% for both retired dancers and controls for total body osteoporosis. The authors of the meta-analysis concluded that disordered eating, menstrual disturbances, and low mineral density are important health issues for dancers of all skill levels, and, that the research into these inter-related conditions is still developing.

In summary, studies show that ballet training has a positive effect on bone density in weight bearing sites such as the hip. The femoral neck of the hip seems to be the site that has equal to, or greater, levels of bone density compared to controls or reference data. Non weight-bearing sites such as the arms are not positively influenced by ballet training, and dancers may have lower bone density in the arms compared to controls. The spine of ballet dancers was frequently reported to have lower bone density levels than control subjects or reference data, although this is not a universal finding across all studies. Therefore, it is important to address total-body bone development in young ballet dancers.

2) The Effect of Delayed Menarche and Amenorrhea on Bone Density in Female Ballet Dancers

In this section, the relationship between bone mineral density, the age of menarche, and menstrual status will be examined. When reading the literature on menstrual dysfunction in dancers, it can be difficult to compare research as the definitions for amenorrhea and oligomenorrhea are not always clearly defined,nor are the definitionsstandardized across the literature.Relevant definitions used within the American College of Sports Medicine position statement of the female athlete triad (Nattiv et al., 2007) are outlined in Table II.

The research included in this section of the review defined delayed menarche as being after the age of fourteen(Warren et al., 2002, Yannakoulia et al., 2004, Hoch et al., 2011, Castelo-Branco et al., 2006, Kadel et al., 1992) whereas primary amenorrhea was defined as up to sixteen years of age (Castelo-Branco et al., 2006). Secondary amenorrhea was defined as 1) the absence of menses for more than three months or cycles (Hoch et al., 2011) (Castelo-Branco et al., 2006, Yannakoulia et al., 2004, Keay et al., 1997) or 90 days after menses (Kadel et al., 1992), or 2) amenorrhea of five months or more immediately preceding the study (Warren et al., 2002). Oligomenorrhea was defined as cycles lasting longer than 32 days (Keay et al., 1997), or 35 days(Hoch et al., 2011), or, longer than 38 days but shorter than 90days (Kadel et al., 1992). No definitions were given for amenorrhea or oligomenorrhea in three studies (Valentino et al., 2001, Doyle-Lucas et al., 2010, Munoz MT, 2004). A summary of the findings of the research used in this section can be seen in Table III.

2.1) Age of Menarche

The age of menarcheinfluences bone density development in females. Normative data for healthy Dutch girls established that an earlier age of menarche was linked to greater lumbar spine and total bone mineral density when girls of the same age were compared (Boot et al., 1997). Girls with regular menses had greater total bone mineral density compared to girls with irregular menses, independent of age (P=0.01) (Boot et al., 1997). Puberty has a positive effect on bone density, as both lumbar spine and total bone mineral density increased significantly throughout the progression of Tanner stage maturation (Boot et al., 1997). These authors reported that late puberty and amenorrhoea were risk factors for lower bone density (Boot et al., 1997).

Ballet dancers tend to have a later menarche than non-ballet dancers (van Marken Lichtenbelt et al., 1995, Kadel et al., 1992), with studies reporting a delay of four months (Castelo-Branco et al., 2006) to over a year (Burckhardt et al., 2011, Doyle-Lucas et al., 2010). Yannakoulia et al. noted that 43.8% of theiradult subjects experienced delayed menarche (Yannakoulia et al., 2004) while other authors have reported that80% of professional ballet dancers had delayed menarche(Kadel et al., 1992).A positive correlation was found by other researchers between years of ballet training before menarche and the age of menarche, meaning that pre-puberty will be prolonged with more years of intense ballet training before puberty (Valentino et al., 2001, Castelo-Branco et al., 2006). Therefore, a delay in the onset of menarche could be detrimental to long-term bone health.

Cross sectional (Castelo-Branco et al., 2006) and longitudinal studies(Warren et al., 2002) of ballet dancers have found a negative influence on bone density development due to delayed menarche. Delayed menarche is negatively correlated to lumbar bone density, meaning that the later the age of menarche, the lower the lumbar spine bone density, (van Marken Lichtenbelt et al., 1995) (Keay et al., 1997). Delayed menarche has also been linked with and increased incidence of stress fractures in ballet dancers (Warren et al., 2002). Stress fractures were used as a measure of functional bone strength in this two year longitudinal study (Warren et al., 2002) and, subjects with stress fractures had an older age of menarche compared to subjects who had not experienced stress fractures (15.2 *vs* 13.5yrs, respectively; p=0.002). Stress fractures were also associated with lower bone mineral density of the spine ($p<0.05$). The authors suggested that a delay in puberty may negate the positive effects of weight bearing exercise (i.e. ballet) on bone growth. However, an older study (Kadel et al., 1992) did not find a significant association between age at menarche and stress fractures. In this study, professional ballet dancers with fractures had a mean age at menarche of 14.6years compared to 15.0 years for dancers without fractures (Kadel et al., 1992). All dancers were of similar age, weight, height, and years of dance training. It is possible that as all the dancers in this study had delayed menarche, the dancers who developed stress fractures had other risk factors for the female athlete triad and bony stress pathology, such as low energy availability. Low energy availability has been identified as being the key component underlying the relationship between the other factors of the female triad (Mountjoy et al., 2014). Therefore, the greater stress fracture rates may not have been attributed to the age of menarche, but possibly to other components such as energy availability. In summary, young female ballet dancers tend to have a later onset of menarche than non-dancers, which may be longer with more years of intense ballet training during pre-puberty.

A delay in menarche reduces the time available for adolescent female dancers to accrue bone mineral density during their growth and development. As a result, dancers with delayed menarche may have reduced bone density in their spine and have increased risk of stress fractures.

2.2) Menstrual Function and Bone Mineral Density

Research into the prevalence of the female athlete triad in dancers clearly identifies that menstrual dysfunction occurs in both adolescent and professional ballet dancers. At a professional level, a survey of the Norwegian national ballet company reported that 70% of the female dancers had a history of menstrual dysfunction (Raastad et al., 2005). Another investigation of professional dancers stated that 23.8% of the dancers had amenorrhoea at the time of the study, compared to 4% of the non-dancer controls who were matched for age, weight, height, and body mass index (Kaufman et al., 2002). These authors also reported that more dancers (52%) had been amenorrheic, in comparison to 14.8% of the controls(Kaufman et al., 2002). Hoch et al (Hoch et al., 2011) determined the prevalence of the female athlete triad in a single professional ballet company, and, out of 22 dancers with a mean age of 23.2 +/- 4.7years, found that 36% had current menstrual dysfunction, 18% had a history of primary amenorrhoea, 64% had a history of secondary amenorrhoea, and 27% had a history of oligomenorrhoea. Although there was no control group in this study, the percentages listed above are quite alarming and worth mentioning.

The adolescent dancer population was examined in a cross-sectional study by Munoz et al.(Munoz MT, 2004). Adolescent ballet dancers and rhythmic gymnasts who trained at least 20 hours a week were compared to non-athletic age and sex matched controls. They found that oligomenorrhea was present in 74% of the adolescent ballet dancers compared to none of the control subjects, all of whom had normal menstrual cycles (Munoz MT, 2004). Therefore, it is clear that menstrual dysfunction occurs inboth adolescent and adult(Hoch et al., 2011, Raastad et al., 2005, Kaufman et al., 2002) ballet dancers.

The negative effect of amenorrhea and menstrual dysfunction on bone density is well recognized. Young adult women who were not athletes or dancers, (mean age 24years) who had secondary amenorrhea or oligo-menorrhea in their adolescence, had lower bone mineral density than age matched reference values (Wiksten-Almstromer et al., 2009). Research has found similar results in young adult ballet dancers (Warren et al., 2002), with those dancers with a history of adolescent menstrual dysfunction having lower total bone density than dancers with a normal menstrual history.A recent meta-analysis found preliminary evidence that menstrual disturbance is linked to the risk of lower bone mineral density in female ballet dancers (Hincapie and Cassidy, 2010). Other authors have also reported that ballet dancers with amenorrhoea have less bone density than ballet dancers and control subjects with normal menses (Doyle-Lucas et al., 2010, Keay et al., 1997, Miller, 1999). If amenorrhea ceases and cycles resume, bone density increases, but not to normal levels. Amenorrheic dancers who regained menses experienced significant increases in wrist and spine bone density, but these levels remained below normal at the end of the two year study period (Warren et al., 2002).

Site-specific differences in bone density have been seen between amenorrheic and eumenorrheic dancers. During a two year longitudinal study (Warren et al., 2002), amenorrheic and eumenorrheic adult ballet dancers and non-exercising controls who were matched for age and height were followed to determine the effects of exercise and hypothalamic amenorrhoea on bone mass accrual in young adulthood. The amenorrheic dancers had significantly lower bone density levels in the lumbar spine compared to the eumenorrheic dancers and control subjects, but the femoral neck bone density was similar to normal levels. Eumenorrheic dancers had significantly greater femoral neck bone density compared to control subjects and also had increased bone density in the wrist and foot compared to amenorrheic dancers at baseline and at the completion of the two year study period(Warren et al., 2002). Together, these data show that the positive effect of ballet training on the hip is reduced by amenorrhea. Although not statistically significant, a trend exists between decreasing bone density levelsand increasing menstrual dysfunction (Doyle-Lucas et al., 2010).

The long term impact of amenorrhea combined with elite ballet training can be seen in the incidence of stress fractures amongst professional adult ballet dancers (Kadel et al., 1992).Only six out of fifty four dancers across two national ballet companies were eumenorrheic. Seventeen dancers had a combined total of twenty-seven stress fractures, with six dancers reporting more than one stress fracture. Of the dancers with fractures, all the dancers had amenorrhea for more than six months. Further analyses revealed that the dancers with stress fractures had a significantly longer duration of amenorrhea than those without a fracture ($P<0.001$). The number of hours of dancing per day was also found to independently increase the risk of stress fractures, with more than five hours a day of dancing having a significantly greater risk than dancing for less than five hours a day. There were eighteen dancers who danced for more than five hours a day, and 50% of these dancers sustained fractures, compared to the 31% of dancers who danced for less than five hours a day and sustained fractures (Kadel et al., 1992). These statistics help explain the relationship between menstrual status, dance demands, and bone health, highlighting the importance of maintaining normal menstrual status among dancers.

Data from retired professional dancers (Khan et al., 1996) show that being a professional dancer itself does not lead to a higher incidence of osteopenia or osteoporosis. These dancers did not have lower bone densities at any of the hip sites compared to the control subjects. However, dancers with a history of menstrual disturbance had 8% lower bone density of the spine and 10% less in the forearm compared to the control group, further adding to the body of evidence that ballet dancing does not have a negative effect on bone density, but menstrual disturbances do.

In summary, amenorrhea reduces bone density levels in female ballet dancers, particularly in the lumbar spine and arms. Secondary amenorrhea in the adolescent years prevents optimal bone density gain in ballet dancers undergoing intense training. Weight bearing sites such as the hip are protected by ballet training, as dancers with a history of amenorrhea may have normal bone density of the hip. Bone density increases if menses resume, but not back to normal levels. As the duration of amenorrhea increases alongside intense ballet training, the risk of stress fractures increases.

2.3) Energy Availability and the Female Athlete Triad

Menstrual dysfunction and sub-optimal bone density are the results of low energy availability, and together these factors have traditionally been termed the female athlete triad. Energy availability is the amount of dietary energy remaining for the other bodily functions after exercise expenditure (Hoch et al., 2011). Low energy availability that occurs unintentionally or intentionally initiates a cascade of physiological changes, which includes alterations in the activity of the hypothalamic pituitary axes and hormones involved in menstrual function and bone metabolism (Barrack et al., 2013). The International Olympic Committee Consensus statement (2014) published a broader definition of relative energy deficiency in sport, expanding upon the prior definition of the female athlete triad: “*the syndrome of relative energy deficiency in sport refers to impaired physiological function including, but not limited to, metabolic rate, menstrual function, bone health, immunity, protein synthesis, cardiovascular health caused by relative energy deficiency*” (Mountjoy et al., 2014).

Likely due in part to the aesthetic demands on ballet and extensive demands of training, low energy availability exists in female ballet dancers, and has been associated with menstrual dysfunction and low bone density. Hoch et al. (Hoch et al., 2011) examined 22 dancers from a single professional ballet company, of whom 77% had low energy availability or an energy deficiency, calculated from a three day food diary and accelerometers worn for 72 hours. The other components of the triad were present, with 36% of dancers self-reporting current menstrual dysfunction, 23% had low bone density in the lumbar spine (Z-score<-1.0 ACSM/WHO criteria), and 9% had low whole-body BMD and lumbar spine BMD.

Doyle-Lucas et al (Doyle-Lucas et al., 2010) measured the prevalence of the female athlete triad components in professional ballet dancers and recreationally active controls (<150min/week of moderate-high intensity exercise a week), matched for age, height, body mass index (BMI), lean body mass, and fat free mass. The professional dancers reported significantly higher moderate and high intensity physical activity per week compared to the controls, of approximately 36 hours per week (more than 5 hours a day; $p \leq 0.01$). However, the dancers had significantly lower energy intake than the control subjects, with resultant significantly lower energy availability ($p \leq 0.01$). In addition, energy availability and resting metabolic rate decreased as menstrual dysfunction increased. Whilst this did not reach significance, dancers with amenorrhoea had the lowest energy intake, absolute and relative metabolic rate, energy availability, and lowest bone mineral density.

Studies of adolescent ballet dancers have investigated energy intake in relation to bone health and/or growth and maturation (Donoso et al., 2010, Munoz MT, 2004, Burckhardt et al., 2011). Energy availability wasn’t calculated, but energy intake was assessed from food diaries. In all studies, the young dancers had insufficient energy intakes for their amount of weekly training, which was above 18hours a week, when compared to Food and Nutrition board of the Institute of Medicine of the National Academy, USA (Munoz MT, 2004, Donoso et al., 2010), or the Swiss Society of Nutrition (Burckhardt et al., 2011).

In summary, adequate energy balance is essential for preventing the cascade of physiological changes associated with low energy availability and the subsequent negative effects on menstrual function and bone health.

3) The Effect of Participation in Ballet Training in Childhood and Adolescence on Bone Density Development

Physical activity in childhood is an important factor in bone development, with different types of exercise having various effects on bone growth and development. Studies on childhood and adolescent participation at elite levels of gymnastics, swimming, running, and triathlons (Courteix et al., 1998, Duncan, 2002) show that prepubescent gymnasts and adolescent runners had higher bone mineral density than the age-matched non-athletic control groups. Although physical activity during childhood is an important factor for bone density development, the type of exercise needs to place sufficient strain on the musculoskeletal system for long term osteogenic effects (Courteix et al., 1998). Ballet can be described as a loaded physical activity, involving jumping, hopping, and skipping, and therefore could provide adequate mechanical strain to create an osteogenic effect. As a result, researchers have investigated the effects of childhood participation in ballet on bone density development.

A longitudinal study (Matthews et al., 2006) followed non-elite pre- and peri-pubertal dance students and non-dancing normally active controls for three years, who were between 8-11 years old at baseline measurements. All participants took part in school sport and physical education classes, but the dance students participated in significantly more hours per week in weightbearing activity across all ages. A limitation of this study is that the dance students participated in ballet as well as other dance styles, so the specific effects of ballet on bone density could not be identified. Controlling for size, body composition, and biological age, the dance students had increased bone mineral content in the femoral neck, lumbar spine, and total bodycompared to the control group. However, the control group had higher bone mineral content in the upper limb throughout the study period. The authors concluded that these results indicate a site-specific adaptation to dance training in the peri-pubertal period. Although it appears that dance training inclusive of ballet seems to increase bone mineral content at the femoral neck, the apparent lack of this phenomenon in the upper limb and lumbar spine suggests that young dancers may also need to participate in some kind of loaded activity involving the upper body to ensure proper bone growth throughout the entire body.

Khan et al. (Khan et al., 2000, Khan et al., 1996, Khan K, 1998) published a series of studies on retired elite ballet dancers in Australia. Control subjects were sourced from a separate study of female twins. One individual from each twin pair was matched to a dancer for age, menopausal status, height and weight. The researchersassessedifchildhood ballet training influenced adult bone mineral density inthe presence of multiple risk factors for osteoporosis due to the lifestyle of professional ballet dancers (Khan et al., 1996). The retired ballet dancers were interviewed regarding their childhood ballet training between the ages of 10-12 years, and lifestyle factors that influence bone density such as calcium intake, smoking, menstrual history, family history, and alcohol intake. There was a positive association between the hours of ballet training at 10-12 years of age, and bone density of the hip in adulthood. The dancers had similar bone density levels of the hip to the control group, even though the dancershad more risk factorsfor low bone density such as smoking, delayed menarche, and menstrual disturbances. The authors suggested that the risk factors for low bone density of the hip were over-ridden by the jumping and landing forces provided by the childhood ballet training. In another study published by this research group (Khan K, 1998), there was no association between the weekly hours of childhood ballet training, or the starting age of ballet, and bone mineral density of the lumbar spine and forearm.

A review by Khan (Khan et al., 2000) found that growth and bone mineral accrual is more associated with maturational stage than chronological age. They suggest that there is evidence that high impact loading of the skeleton before skeletal maturation can positively affect bone mineral accrual. This matches the findings of Matthews et al. (Matthews et al., 2006), who reported that pre-pubertal dancers had 4% higher bone mineral content in the femoral neck of the hip ($P<0.05$) compared to the non-dancer control group, when maturational differences were controlled. This advantage in the dancers was identified at the commencement of the three-year longitudinal study, and it remained through the duration of their study. These authors suggested that the increased bone densityof the hip was due to dance training prior to puberty.

A 36 month prospective follow up study of twenty two ballet students, average age 11 years at baseline, measured the bone mineral density of the lumbar spine, femoral neck, the femoral trochanter region, inter-trochanter region and Ward's triangle(Donoso et al., 2010). The ballet students trained for over 18 hours a week at a national ballet school, whereas the control group were local school children who performed less than 3 hours of exercise per week. The ballet dancers' bone density levels in all locations were normal, but there was a delay in the onset and progress of puberty. Bone maturation was also delayed, though this reduced as puberty progressed. The authors surmised that the maturational delays were caused by insufficient energy intake for the quantity of physical activity undertaken during this period of growth and development. These studies show that there is a site-specific effect of weight bearing exercise on bone density development.

Due to ballistic movements such as jumping, hopping, and skipping, ballet training has a positive effect on the hip, but not on the upper body or lumbar spine.

Resistance Training as a Strategy to Improve Bone Health

It has been determined through this literature review that ballet training has anosteogenic effect on the skeletal system, even in the presence of low energy availability and menstrual dysfunction. However, ballet has a positive effect only in specific sites, notably the hip, and does not have an osteogenic effect on the upper body or the spine. It is important therefore, for dancers to participate in other physical activities that load the rest of the skeletal system, particularly young, growing dancers who need to optimise their total-body bone development. Resistance training has been recommended as a non-pharmacological strategy for improving bone health in the context of the female athlete triad(Mallinson and De Souza, 2014, Ducher G, 2011, De Souza et al., 2014, Javed A, 2013).Bone tissue is highly responsive to high impact and high magnitude loading as well as strength training; therefore, a combined programme of high impact loads and strength training is a possible method of optimizing bone health in ballet dancers and any other athletes who are subjected to similar activity and dietary patterns (De Souza et al., 2014).Concerns exist within the literature regarding females with low bone density and/or fractures participating in high impact activity, and further research is necessary in this area(De Souza et al., 2014). To date, there has been no published research investigating the effects of resistance training and/or high impact training on bone health in ballet dancers. The ballet community has traditionally stayed away from strength training due to the fear of it adding unwanted muscle bulk. However, with the growing recognition that dancers are performing athletes (Koutedakis Y, 2004) who need to undertake additional fitness and cross training exercise to assist their injury prevention and performance (Koutedakis Y, 2005, Koutedakis Y, 1997), it may be more acceptable now than in previous years. It should also be noted that energy intake must be monitored with any additional physical training added to a dancers' schedule (Mallinson and De Souza, 2014). Therefore, it is advised that dancers, parents, and all other involved parties should seek guidance from certified strength and conditioning specialists in conjunction with sports nutritionists before partaking in a structured strength-training program.

Conclusions and practical applications

Delayed menarche and amenorrhea decrease bone mineral density and may increase the risk of stress fracture in female ballet dancers. Therefore, it is important to prevent, or minimize, the delay in menarche to allow for optimal bone gain post menarche during adolescence. Early detection of any delays in puberty is recommended (Burckhardt et al., 2011).

Moreover, education should be provided to ballet students, their families, and ballet teachersabout the importance of puberty for bone development in adolescent female ballet dancers, in addition to the negative consequences of delaying puberty by inadequate weight gain and dieting. Education regarding nutrition and eating habits should also be provided, especially to young ballet students (Doyle-Lucas et al., 2010).

To help foster eumenorrhea, appropriate weight gain during growth should also be encouraged, simply determined by achieving a minimum BMI of 16kg/m^2 at age 15, 16.4kg/m^2 at age 16, 16.8 kg/m^2 at age 17, and 17 kg/m^2 at age 18 (Burckhardt et al., 2011).

With regards to educating ballet dancers themselves, aspiring ballet dancers maybe more receptive to information that helps them minimize their short-term injury risks compared to long-term health effects. Using examples such as increased stress fractures may be more effective at affecting behaviour change, whereas a teenager may not acknowledge the possibility of osteoporosis in the future. It is also important to provide encouragement and acceptance around girls getting their periods regularly. Dancers, their family members, and their teachers should create a culture amongst the female students that the onset of menarche is a good thing, and not an inconvenience. Lastly, fostering a culture of healthy relationships with food and body image within the ballettraining environment should be emphasized.

To summarize, the following points must be addressed in order to help improve and maintain bone health among female ballet dancers:

- Ballet training can have a positive impact on bone density development on weight bearing sites, particularly the hip.
- Female dancers who have amenorrhea and/or a delay in the age of menarche are more likely to have lower bone density than those dancers with normal menstrual function and menarche.
- It is of paramount importance to have a multidisciplinary support network to monitor ballet students' growth and development, and to identify those students with delayed menarche, energy insufficiency, or menstrual dysfunction.
- With guidance from a certified strength and conditioning coach and sports dieticians, dancers of all ages should participate in physical activity other than ballet such as strength training to ensure whole body skeletal loading.

References

- BARRACK, M. T., ACKERMAN, K. E. & GIBBS, J. C. 2013. Update on the female athlete triad. *Curr Rev Musculoskelet Med,* 6**,** 195-204.
- BOOT, A. M., DE RIDDER, M. A. J., POLS, H. A. P., KRENNING, E. P. & DE MUINCK KEIZER-SCHRAMA, S. M. P. F. 1997. Bone mineral density in children and adolescents: relation to puberty, calcium intake and physical activity. *Journal of Clinical Endocrinology and Metabolism,* 82**,** 57-62.
- BURCKHARDT, P., WYNN, E., KRIEG, M.-A., BAGUITTI, C. & FAOUZI, M. 2011. The effects of nutrition, puberty and dancing on bone density in adolescent ballet dancers. *Journal of Dance Medicine and Science,* 15**,** 51-60.
- CASTELO-BRANCO, C., REINA, F., MONTIVERO, A. D., COLODRON, M. & VANRELL, J. A. 2006. Influence of high-intensity training and of dietetic and anthropometric factors on menstrual cycle disorders in ballet dancers. *Gynaecological Endocrinology,* 22**,** 31-5.
- COURTEIX, D., LESPESSAILLES, E., LOISEAU PERES, S., OBERT, P., GERMAIN, P. & BENHAMOU, C. L. 1998. Effect of physical training on bone mineral density in pre pubertal girls: a comparative study between impact-loading and non-impact loading sports. *Osteoporosis International,* 8**,** 152-158.
- CUESTA, A., REVILLA, M., VILLA, L. F., HERNANDEZ, E. R. & RICO, H. 1996. Total and regional bone mineral content in Spanish professional ballet dancers. *Calcified Tissue International,* 58**,** 150-154.
- DE SOUZA, M. J., NATTIV, A., JOY, E., MISRA, M., WILLIAMS, N. I., MALLINSON, R. J., GIBBS, J. C., OLMSTED, M., GOOLSBY, M., MATHESON, G. & EXPERT, P. 2014. 2014 Female Athlete Triad Coalition Consensus Statement on Treatment and Return to Play of the Female Athlete Triad: 1st International Conference held in San Francisco, California, May 2012 and 2nd International Conference held in Indianapolis, Indiana, May 2013. *Br J Sports Med,* 48**,** 289.
- DONOSO, M. A., MUNOZ-CALVO, M. T., BARRIOS, V., GARRIDO, G., HAWKINS, F. & ARGENTE, J. 2010. Increased circulating adiponectin levels and decreased leptin/soluble leptin receptor ratio throughout puberty in female ballet dancers: association with body composition and the delay in puberty. *European Journal of Endocrinology,* 162**,** 905-11.
- DOYLE-LUCAS, A. F., AKERS, J. D. & DAVY, B. M. 2010. Energetic inefficiency, menstrual irregularity, and low bone mineral density in elite professional female ballet dancers. *Journal of Dance Medicine and Science,* 14**,** 146-154.
- DUCHER G, T. A., KUKULJAN S, PANTANO KJ, CARLSON JL, WILLIAMS NI, DE SOUZA MJ. 2011. Obstacles in the optimisation of bone health outcomes in the female athlete triad. *Sports Medicine,* 41**,** 587-607.
- DUNCAN, C. S., BLIMKIE, C.J.R, COWELL, C.T, BURKE, S.T, BRIODY, J.N, HOWMAN-GILES, R 2002. Bone mineral density in adolescent female athletes:relationship to exercise type and muscle strength. *Medicine and Science in Sport and Exercise,* 34**,** 286-294.
- HINCAPIE, C. A. & CASSIDY, J. D. 2010. Disordered eating, menstrual disturbances, and low bone mineral density in dancers: a systematic review. *Archives of Physical Medicine and Rehabilitation,* 91**,** 1777-1789 e1.
- HOCH, A. Z., PAPANEK, P., SZABO, A., WIDLANSKY, M. E., SCHIMKE, J. E. & GUTTERMAN, D. D. 2011. Association between the female athlete triad and endothelial dysfunction in dancers. *Clin J Sport Med,* 21**,** 119-25.
- JAVED A, T. P., FISCHER PR, LTEIF AN, 2013. Female athletic triad and its components: towrd improving screening and management. *Mayo Clinic Proceedings,* 88**,** 996-1009.
- KADEL, N. J., TEITZ, C. C. & KRONMAL, R. A. 1992. Stress fractures in ballet dancers. *American Journal of Sports Medicine,* 20**,** 445-449.
- KAUFMAN, B. A., WARREN, M. P., DOMINGUEZ, K. J., WANG, J., HEYMSFIELD, S. B. & PIERSON, R. N. 2002. Bone density and amenorrhoea in ballet dancers are related to decreased resting metabolic rate and lower leptin levels. *The Journal of Clinical Endocrinology and Metabolism,* 87**,** 2777-2783.
- KEAY, N., FOGELMAN, I. & BLAKE, G. 1997. Bone mineral density in professional female dancers *British Journal of Sports Medicine,* 31**,** 143-147.
- KHAN K, B. K., HOPPER JL, FLICKER L, NOWSON CA, SHERWIN AJ, CRICHTON KJ, HARCOURT PR, WARK J 1998. Self-reported ballet classes undertaken at age 10-12 years and hip bone mineral density in later life. *Osteoporos Int,* 8**,** 165-173.

- KHAN, K., MCKAY, H. A., HAAPSALO, H., BENNELL, K. L., FORWOOD, M. R., KANUS, P. & WARD, J. D. 2000. Does childhood & adolescence provide a unique opportunity for exercise to strengthen the skeleton? *Journal of Science and Medicine in Sport,* 3**,** 150-164.
- KHAN, K. M., GREEN, R. M., SAUL, A., BENNELL, K. L., CRICHTON, K. J., HOPPER, J. L. & WARK, J. D. 1996. Retired elite female ballet dancers and nonathletic controls have similar bone mineral density at weightbearing sites. *Journal of Bone and Mineral Research,* 11**,** 1566-1574.
- KOUTEDAKIS Y, J. A. 2004. The dancer as a performing athlete: physiological considerations. *Sports Medicine,* 34**,** 651-661.
- KOUTEDAKIS Y, K. M., PACY PJ, MURPHY M, DUNBAR GMJ, 1997. Thigh peak torques and lower-body injuries in dancers. *Journal of Dance Medicine & Science,* 1**,** 12-15.
- KOUTEDAKIS Y, S.-K. A., METSIOS G. 2005. The significant of muscular strength in dance. *Journal of Dance Medicine & Science,* 9**,** 29-34.
- MALLINSON, R. J. & DE SOUZA, M. J. 2014. Current perspectives on the etiology and manifestation of the "silent" component of the Female Athlete Triad. *Int J Womens Health,* 6**,** 451-467.
- MATTHEWS, B. L., BENNELL, K. L., MCKAY, H. A., KHAN, K. M., BAXTER-JONES, A. D., MIRWALD, R. L. & WARK, J. D. 2006. Dancing for bone health: a 3-year longitudinal study of bone mineral accrual across puberty in female non-elite dancers and controls. *Osteoporosis International,* 17**,** 1043-54.
- MILLER, K. K. A. 1999. Clinical review 106: Amenorrheic bone loss *Journal of Clinical Endocrinology and Metabolism,* 84**,** 1775-1783.
- MOUNTJOY, M., SUNDGOT-BORGEN, J., BURKE, L., CARTER, S., CONSTANTINI, N., LEBRUN, C., MEYER, N., SHERMAN, R., STEFFEN, K., BUDGETT, R. & LJUNGQVIST, A. 2014. The IOC consensus statement: beyond the Female Athlete Triad--Relative Energy Deficiency in Sport (RED-S). *Br J Sports Med,* 48**,** 491-7.
- MUNOZ MT, D. L. P. C., BARRIOS V., GARRIDO G., ARGENTE J. 2004. Changes in bone density and bone markers in rhythmic gymnasts & dancers: implications for puberty and leptin levels. *European Journal of Endocrinology,* 151**,** 491-196.
- NATTIV, A., LOUCKS, A. B., MANORE, M. M., SANBORN, C. F., SUNDGOT-BORGEN, J., WARREN, M. P. & AMERICAN COLLEGE OF SPORTS, M. 2007. American College of Sports Medicine position stand. The female athlete triad. *Medicine and Science in Sports and Exercise,* 39**,** 1867-82.
- RAASTAD, R. S., RAASTAD, T. & SUNDGOT-BORGEN, J. 2005. Prevalence of the female athletic triad in the Norwegian National Ballet, Selected Abstracts from the 15th Annual Meeting of the International Association for DanceMedicine & Science. *Journal of Dance Medicine and Science,* 9**,** 63.
- RUFF, C., HOLT, B. & TRINKAUS, E. 2006. Who's afraid of the big bad Wolff?: "Wolff's law" and bone functional adaptation. *Am J Phys Anthropol,* 129**,** 484-98.
- SOYKA, L. A., FAIRFIELD, L. P. & KLIBANSKI, A. 2000. Hormonal determinants and disorders of bone mass in children. *Journal of Clinical Endocrinology and Metabolism,* 85**,** 3951-3963.
- TAAFFE, D. R., ROBINSON, T. L., SNOW, C. M. & MARCUS, R. 1997. High-impact exercise promotes bone gain in well trained female athletes. *Journal of Bone and Mineral Research,* 12**,** 255-260.
- VALENTINO, R., SAVASTANO, S., TOMMASELLI, A. P., AMORE, G., DORATO, M. & LOMBARDI, G. 2001. The influence of intense ballet training on trabecular bone mass, hormone status, and gonadotropin structure in young women. *The Journal of Clinical Endocrinology and Metabolism,* 86**,** 4674-4678.
- VAN MARKEN LICHTENBELT , W. D., FOGELHOLM, M., OTTENHEIJM, R. & WESTERTERP, K. 1995. Physical activity, body composition and bone density in ballet dancers. *British Journal of Nutrition,* 74**,** 439-451.
- WARREN, M. P., BROOKS-GUNN, J., FOX, R. P., HOLDERNESS, C. C., HYLE, E. P. & HAMILTON, W. G. 2002. Osteopenia in exercise-associated amenorrhoea using ballet dancers as a model: a longitudinal study. *The Journal of Clinical Endocrinology and Metabolism,* 87**,** 3162-3168.
- WIKSTEN-ALMSTROMER, M., HIRSCHBERG, A. L. & HAGENFELDT, K. 2009. Reduced bone mineral density in adult women diagnosed with menstrual disorders during adolescence. *Acta Obstetricia et Gynecologica* 88**,** 543-9.
- YANNAKOULIA, M., KERAMOPOULOS, A. & MATALA, A. L. 2004. Bone mineral density in young active females: the case of dancers. *International Journal of Sport Nutrition and Exercise Metabolism,* 14**,** 285-297.

Table I: Bone density levels in dancers

Studies with Adult Subjects			
Author(s), Year	Subjects & Study Design	Age	Results
Cuesta et al., (1996)	Spanish National Dance Company members (n=15) Non-dancer normal age matched controls (n=15)	25.1 y 26.1 y	• Bone mineral content (BMC) dancers < controls in arms (p<0.05) & in trunk without pelvis (p<0.005) • Absolute and relative total body BMC was not significantly different between dancers and controls • Lower trunk BMC is a risk factor for osteoporosis in female dancers
Doyle-Lucas, Akers & Davy, (2010)	Professional ballet dancers (n=15) University student controls (n=15)	24.3 y 23.7 y	• No significant differences in total bone mineral density (BMD), femoral neck Z-scores, or spine Z-scores between groups • BMD levels for eumenorrheic controls >eumenorrheic dancers > dancers with menstrual dysfunction • Lower spine BMD in dancers with menstrual dysfunction (not significant, p-value not reported)
Hoch et al., (2011)	Professional ballet dancers (n =22)	23.2 y	• Low BMD was defined as Z-Score < -1.0 according to the World Health Organisation/American College of Sports Medicine • 23% of dancers had low BMD in the lumbar spine • 9% had low BMD in the lumbar spine and total BMD • no dancers had low BMD of the femoral neck or trochanter
Kaufman, (2002)	Professional ballet dancers (n=21) Non-dancers (n=27)	23.2 y 24.5 y	• No significant difference in total BMC or leg BMD between groups • Dancers with history of amenorrhea had significantly lower metabolic rate and BMD
Keay, Fogelman & Blake, (1997)	Retired and current professional ballet dancers (n=48)	36.0 y	• Eumenorrheic dancers' femoral neck BMD significantly above normal population (P<0.05) • Eumenorrheic dancers' lumbar spine BMD average Z-scores were not

	Retired and current contemporary dancers (n=9)		significantly different to the normal population • Eumenorrheic dancers' femoral neck average Z-scores were significantly above the normal population (P<0.01) • Amenorrheic dancers' lumbar spine average Z-scores were significantly lower than the normal population (P<0.01) • Amenorrheic dancers' femoral neck Z-scores were not significantly different to normal population
Khan et al., (1996)	Retired professional ballet dancers (n=101) Controls (n=101)	51.0 y 51.0 y	• No difference in hip BMD between groups • 10% less radius BMD in dancers • 8% lumbar less spine BMD in dancers
Van Marken Lichtenbelt et al., (1995)	Professional & student ballet dancers (n=24) Controls – reference data used (n=24)	22.6 y	• Greater average total BMD in dancers (95%CI>100%), due to high BMD in the legs and pelvis • BMD of head and arms were not significantly different between groups
Valentino et al (2001)	Current dancers (n=20) Ex-dancers (n=9) Age-matched non-active controls (n=30)	21.5 y 22.3 y 22.5 y	• Lumbar spine BMD significantly less in dancers (p<0.05)
Yannakoulia, Keramopoulos & Hagenfeldt, (2009)	Elite ballet dancers (n=37) Controls – reference data used	20.7 y	• Dancers' mean total BMD 9% > reference data • Dancers' mean and regional arm BMD 5% and 16% > reference data, respectively

Studies with Child and/or Adolescent Subjects			
Author(s), Year	Subjects & Study Design	Age	Results
Burkhardt et al., (2011)	Elite elite ballet students, (n=127) Controls - reference data used	16.0 y	• Significantly greater femoral neck BMC in dancers compared to reference data (P<0.01) • 37% of dancers had lumbar spine BMC below 5th percentile
Donoso et al., (2010)	Elite ballet students (n=22) Non-dancing healthy controls (n=30), at three different stages of puberty, age & weight matched	11.3 y 10.5 y 11.9 y 15.1 y	• Normal BMD in all locations compared to control group
Matthews et al., (2006)	Non elite dancers (n=82) Normally active non-dancing controls (n=61)	8-11 y at baseline 8-11 y at baseline	• Significantly greater BMC in dancers – total body, lower limbs, femoral neck, and lumbar spine when adjusted for maturation (p<0.05). These differences were observed peri-puberty, at 1 year post peak height velocity, and by 2 years post PHV, the differences were 0.6%-1.3% greater BMC than controls (P<0.05). • Dancers had 4% (p<0.05) higher BMC of the femoral neck pre-puberty than controls and this was maintained through puberty
Munoz, et al (2004)	Rhythmic gymnasts (n=9) Ballet dancers (n=12) Age-matched controls (n=14)	16.2 y 16.4 y 16.9 y	• Significantly delayed bone age of an average of 2 years in gymnasts & dancers when compared to controls • Normal lumbar spine, all groups • Gymnasts significantly greater hip BMD than dancers & controls (p<0.05) • Less forearm BMD in gymnasts & dancers (p<0.05)

Table II: American College of Sports Medicine Position Stand on the Female Athlete Triad (2007).

Eumenorrhea	Menstrual cycles at intervals near the median interval for young adult women. This is 28 days, with a standard deviation of 7 days.
Oligomenorrhea	Menstrual cycles longer than 35 days.
Amenorrhea • Primary Amenorrhea • Secondary amenorrhea	Absence of menstrual cycles for more than three months • The delay in the age of menarche. Defining age is 15 years. • Amenorrhea that begins after menarche.

Table III: Interactions between menstrual status and bone mineral densityin female ballet dancers

Author(s), Year	Subjects & Study Design	Age	Results
Doyle-Lucas, Akers & Davy (2010)	Professional ballet dancers (n=15) Controls (n=24)	24.3y 23.7y	• Significantly delayed menarche in dancers ($P<0.05$) • Total-scoresfrom eumenorrhoic controls>eumenorrhoic dancers>oligomenorrhoic dancers>amenorrhoic dancers, however these did not reach significance
Kadel, Teitz & Kronmal (1992)	Professional ballet dancers (n=52)	20.2y	• 80% of dancers had delayed menarche • Mean age of menarche = 14.8yrs • No significant association between age of menarche and stress fractures • Duration of amenorrhoea >6 months increased the risk of stress fracture ($P=0.002$) • Duration of amenorrhoea was significantly longer in dancers with stress fractures ($p<0.001$)
Keay, Fogelman & Blake (1997)	Classical dancers (n=48) Contemporary dancers (n=9)	36.0y	• Average Z-score for Lx BMD was significantly below normal ($p<0.01$) in amenorrheic dancers, but femoral neck BMD was not significantly different to normal population • Z-scores for eumenorrheic dancers for femoral neck were above normal population ($p<0.01$), and, at similar levels in Lx spine • Significant differences between amenorrheic and eumenorrheic dancers: BMD of lumbar spine was lower in amenorrheic ($p<0.025$) and BMD of femoral neck was higher in eumenorrheic dancers ($p<0.025$)
Khan et al (1996)	Ex-professional ballet dancers (n=101) Age, height, weight & menopausal status	51.0 y 51.0 y	• No differences in mean BMD at hip sites and lumbar spine between retired dancers and controls • Dancers who had fewer than 5 periods per year during their dancing years have 8% less spine BMD and 10% less forearm BMD than controls

	matchedcontrols (n=101)		• Menstrual dysfunction was negatively correlated with BMD of forearm and lumbar spine, but not at the hip
Matthews et al (2006)	Non- elite dancers (n=82) Controls (n=61)	8-11 y at baseline 8-11 y at baseline	• Age of menarche significantly later in dancers (3.6mths; P<0.05) but within healthy range
Warren et al (2002)	Normal controls (n=22) Normal dancers (n=21) Non-exercise-associated hypothalamic amenorrheic controls (n=22) Amenorrheic dancers (n=10)	22.4 y	• Age of menarche significantly higher in amenorrheicdancers and controls (p<0.05) • Subjects with stress fractures showed an older age of menarche (15.2 vs 13.5 years; ; P=0.002) • BMD was significantly lower at baseline measurements in amenorrheic subjects. • BMD spine ↑12.1% across the 24month study period of amenorrheic dancers, but remained below normal • Eumenorrheic dancers and controls had significantly greater BMD in spine compared to amenorrheic subjects at baseline and throughout study (P<0.001) • Subjects who resumed menses had significant increases in BMD but this did not reach normal levels (17% in wrist and spine; P<0.001) • Wrist BMD significantly greater in eumenorrheic subjects P • Increased frequency of stress fractures associated with less spine BMD (p<0.05)
Yannakoulia, Keramopoulos & Matala (2004)	Elite dance students (n=37) Controls - reference data used	20.7y	• 43.8% of subjects experienced delayed menarche • Current menstrual status did not affect total BMD • Adolescent menstrual history didinfluence BMD. Dancers who reported adolescent menstrual dysfunction had significantlyless total BMD, after controlling for age (p=0.037)