THE FEMALE ATHLETE TRIAD IN GYMNASTICS

Theofanis Siatras[1], Dimitra Mameletzi[2]

[1]Laboratory of Exercise Physiology–Ergometry, Department of Physical Education and Sport Sciences, Aristotle University of Thessaloniki, Greece
[2]Sports Medicine Laboratory, Department of Physical Education and Sport Sciences, Aristotle University of Thessaloniki, Greece

Review article

Abstract

The female athlete triad consists of three interrelated components: low energy availability (with or without eating disorders), amenorrhea and osteoporosis. Female gymnastics is a sport characterized by regular exposure to high-impact prolonged physical training at an early age, requiring strict control of energy consumption. Could this lead to the female athlete triad? The bibliographic data bases of PubMed, Scopus and ScienceDirect were used to identify relevant articles, using appropriate key words as Athletic triad, Eating disorders, Amenorrhea, Osteoporosis, Bone mineral density, Bone mass, Gymnastics and Adolescent. One hundred and thirty six papers were selected and their review was mainly focused on the occurrence of eating disorders, amenorrhea and osteoporosis in female gymnasts. The bibliography revealed that in gymnastics, each component of the female athlete triad alone or a combination of them may occur. It was concluded that, even though the mechanical loading on the female gymnast's skeleton has a site-specific beneficial effect on bone mineral density, it cannot offset the detrimental effect of hormonal deficiency on the skeleton caused by chronic energy deficiency. Low energy availability (with or without eating disorders), menstrual disorders and premature osteoporosis may lead to decreased athletic performance and adverse long-term health consequences. A concerted effort among coaches, athletic trainers, parents, athletes, and healthcare personnel is optimal for the prevention, early diagnosis and treatment of the female gymnasts' athlete triad to preserve their health.

Keywords*: Eating disorders, Amenorrhea, Osteoporosis, Gymnastics*

INTRODUCTION

Female adolescents and young women engaged in strenuous sports activities often manifest a health-related syndrome recognized as the female athlete triad. The female athlete triad consists of three inter-related components: low energy availability (with or without eating disorders), amenorrhea and osteoporosis (Nattiv et al, 2007). These clinical conditions may lead to athletic performance deterioration and long-term health consequences, such as diminished quality of life, morbidity and even mortality (Nattiv et al, 2007; Sanborn et al, 2000). The female athlete triad has been identified in all competitive levels and ages, in high school, collegiate, highly competitive and elite athletes (Barrack, Rauh, & Nichols, 2008b; Beals & Hill, 2006; Cobb et al, 2003; Hoch, Stavrakos & Schimke, 2007; Hoch et al, 2009; Korsten-Reck, 2011; Morgenthal, 2002; Nichols et al, 2006; Thein-Nissenbaum & Carr, 2011a; Torstveit & Sundgot-Borgen, 2005 b; Zach, Smith & Hoch, 2011). Inadequate nutrition, menstrual status, training intensity and frequency, body size and composition, psychological and physiological stress are some of the syndrome's proposed causal factors (Morgenthal, 2002; Yeager et al, 1993).

Sports in which strenuous training is combined with emphasized leanness may predispose girls to increased risk of skeletal and reproductive health problems (McManus & Armstrong, 2010). Adolescents and young women engaged in intensive athletic activity often experience chronic energy deficiency, caused by restricted calorie intake (as in disordered eating), excessive exercise (as in high intensity training), or the combination of both (Wheatley et al, 2012). This has significant health consequences, such as hypothalamic amenorrhea, infertility, attainment of low peak bone mass and bone loss leading to fracture (Chan & Mantzoros, 2005; Rackoff & Honig, 2006; Wheatley et al, 2012). Evidence has shown that athletes most at-risk for the female athlete triad are those participating in endurance, aesthetic and weight classification sports, where a leaner build favours athletic performance, appearance is judged or low body weight is the norm (Lebrun, 2006; Loucks & Nattiv, 2005; Torstveit & Sundgot-Borgen, 2005a; Torstveit & Sundgot-Borgen, 2005c). In addition, athletes practicing individual sports appear to be at higher risk than those participating in team sports (Morgenthal, 2002). Therefore, sports considered to be more high-risk than others are long distance running, figure skating, rhythmic sportive gymnastics, artistic gymnastics, martial arts, diving, synchronized swimming and dance (Barrack et al, 2010; Barrow & Saha, 1988; Beals & Manore, 2002; Cobb et al, 2003; Herbrich et al, 2011; Hulley et al, 2007; Kerr, Berman & De Souza, 2006; Lebrun, 2006; Rooks & Corwell, 2006; Waldrop, 2005; Weimann, 2002; Wheatley et al, 2012; Williams, 1984).

Research indicates that social, environmental and personal factors may contribute to the development of the female athlete triad. In fact, psychocognitive functions, personality traits (e.g. perfectionism, obsessiveness), conflicts between performance and expectations, disturbed eating attitudes and behaviours, maladaptive coping mechanism with stress and social relationships with coaches and peers are found to be related with the occurrence of the female athlete triad (Bachner-Melman et al., 2006; Korsten-Reck, 2011; Nagel, 2003; Scoffier, Maoano & d'Arripe-Loungeville, 2010; Wheatley et al, 2012). In addition, a misplaced belief regarding body weights and performance has been noted, with the coaches frequently pressuring female athletes to lose weight or maintain a low body weight via restricted eating. Thus, they inadvertently induce eating disorders with their beliefs, coaching styles and attitudes (Martinsen et al, 2010; Muscat & Long, 2008; Nagel, 2003).

Each of the female athlete triad's components alone has detrimental effects in athletes' health, but the presence of all three components can have significant health consequences, including anaemia, damage and inadequate repair of soft tissue, endocrine abnormalities, altered reproductive function, impaired bone formation, stress fractures, inhibition of immune and thyroid function, adverse effects on renal function, endothelial dysfunction and cardiovascular disturbances (Cobb et al, 2003; Lanser et al, 2011; Lebrun, 2006; Matejek et al, 1999; Morgenthal, 2002). However, low energy availability seems to be the key disorder underlying the other components of the syndrome (Nattiv et al, 2007). Gymnastics represents an adjudicated sport with a subjective scoring based both on athletic performance and appearance, where reduced weight is associated with enhanced performance (Engel et al, 2003). Thus, it has been shown that it is associated with increased risk for eating disorders (Engel et al, 2003; Kerr, Berman & De Souza, 2006; Krentz & Warschburger, 2011; Rosen & Hough, 1988). Additionally, the incidence of menstrual dysfunctions in gymnasts is high (Bale, Doust & Dawson, 1996; Baxter-Jones et al, 1994; Erlandson et al, 2007; Otis, 1992; Robinson et al, 1995). The combination of eating disorders and athletic amenorrhea has many adverse consequences with the most serious health risk appearing to be the adverse effects on bone mineral density in girls and young women (Morgenthal, 2002). However, gymnastics is considered as one of the most osteogenic sports that induces benefits in cortical and trabecular bone in the peripheral and axial skeleton (Bareither, Grabiner & Troy, 2008; Courteix et al, 1999; Laing et al, 2002; Nickols-Richardson & O'Connor, 1999; Vicente-Rodriguez et al, 2007).

The aim of this review article was to examine the relationship between the female athlete triad and gymnastics. The bibliographic research was limited in three electronic databases. PubMed, Scopus and ScienceDirect were used to identify relevant articles in English language. The key words used to detect appropriate articles were Athletic triad, Eating disorders, Amenorrhea, Osteoporosis, bone mineral density, Bone mass, Gymnastics, Adolescent. The review of the literature was mainly focused on the co-occurrence of eating disorders, amenorrhea and osteoporosis in female gymnasts.

EATING DISORDERS IN FEMALE GYMNASTS

Low energy availability in athletes may be either due to increased energy expenditure or reduction in dietary caloric intake. It has been reported that female teenager gymnasts had an energy intake significantly below the estimated energy need (Lindholm et al, 1995). Low energy availability may occur without eating disorders (Nattiv et al, 2007). However, eating disorders is the most frequently recorded component of the female athlete triad among athletes (Barrack et al, 2008a; Hoch et al, 2009; Nichols et al, 2006). In order to achieve a specific sport ideal body weight, female athletes often become overly concerned with it, thus increasing the tendency for disordered eating behaviours. They involve abnormal eating behaviours, anorexia or bulimia nervosa that can result in morbidity, decreased performance, menstrual abnormalities and mortality (Beals & Manore, 2000; Morgenthal, 2002; Thein-Nissenbaum et al, 2011b; Torstveit & Sundgot-Borgen, 2005).

A study on the prevalence of eating disorders in elite athletes found that it was higher in athletes competing in leanness-related and weight-dependent sport disciplines than in other sports. In particular, the prevalence of eating disorders among female athletes competing in aesthetic sports was higher than that observed in endurance, technical, and ball game sports (42%, 24%, 17% and 16% respectively) (Sundgot-Borgen & Torstveit, 2004). Similarly, Smolak, Murnen & Ruble (2000) suggested that female athletes, competing in elite level sports requiring a lean body, were at a higher risk for eating disorders. Gymnastics is an aesthetic "thin-build" sport that requires a strict control of energy consumption combined with a high-energy expenditure, especially in a highest competitive level. A prevalence of 31% of eating disorders in elite female athletes in sports, that emphasise a lean body shape or a low body weight, has been observed by Byrne and McLean (2002). Additionally, significantly greater percentages of eating disorders have been reported by athletes competing in aesthetic sports as compared to those in endurance and team sports (Beals & Manore, 2002; Krentz & Warschburger, 2011; Thein-Nissenbaum et al, 2011b). In gymnastics, a prevalence of 62% of disordered eating behaviours in collegiate gymnasts was recorded by Rosen & Hough (1988). Torstveit, Rosenvinge & Sundgot-Borgen, (2008) also reported that there are more cases of eating disorders among elite female gymnasts (32.4%) than in non-athletes (1-6%) (Torstveit, Rosenvinge &

Sundgot-Borgen, 2008). Moreover, Petrie (1993) found that, despite reporting moderate body satisfaction and having a BMI in the low-to-healthy range, 61% of the study's female collegiate gymnasts exhibited some sort of eating disorders. Another study suggested that the disordered weight control behaviours collegiate gymnasts mostly practiced were binge eating, excessive exercise and fasting or strict dieting (Petrie & Stoever, 1993). Likewise, Engel and coworkers (2003) found that gymnastics and wrestling were associated with heightened food restriction and athletes in these sports demonstrated elevated levels of purging and vomiting behaviour compared to other athletes.

In female athletes, the initiation of dieting and/or excessive exercising is either voluntary (when they compare their degree of fatness with that of other more successful athletes) or based on coaches' and trainers' recommendations (Sudi et al, 2004). Factors considered to be associated with eating disorders include early start of training, frequent weight fluctuations, prolonged dieting periods, the belief about the need for low body weight for good athletic performance, a sudden increase in training volume, pressure from important others to reduce weight (parents, coaches), lack of weight loss guidance, low self-esteem, fear of puberty in female athletes, injury and overtraining, fear of failing and causal comments (Morgenthal, 2002; Rome et al, 2003; Sundgot-Borgen, 1994). As reported by Krentz & Warschburger (2011), athletes more at risk for eating disorders believe they could improve their athletic performance by weight reduction. In elite female artistic gymnasts, performance scores are negatively correlated with the degree of fatness or endomorphy of the athlete (Claessens et al, 1999). Therefore, trainers usually encourage gymnasts to lose weight, often by making inappropriate comments. In a study by Rosen and Hough (1988), 75% of the athletes, who were told to lose weight by coaches, began to use unhealthy weight control methods. Previous research showed that weight-related teasing and body disparagement might have a significant negative impact on body image and eating behaviours in adolescent females (Van den Berg et al, 2002). Similarly, Kerr, Berman and De Souza (2006) found that gymnasts receiving from coaches disparaging comments concerning their bodies were significantly more likely to engage in unhealthy weight control practices and to report eating disorders. The authors concluded that, disordered eating behaviours occur in gymnastics and they are often endorsed, either implicitly or explicitly, by coaches and the sport context.

It seems that the combination of reduced dietary energy intake and increased exercise energy expenditure results in low energy availability and contributes to the development of eating disorders. Despite adequate training levels, disordered eating in athletes may lead to overtraining syndrome, chronic fatigue, impaired athletic performance and increased risk of injury. In addition, the occurrence of low energy availability affects the secretion of hormones, such as insulin, cortisol, growth hormone, insulin-like growth factor-I, leptin and substrates, such as glucose, fatty acids and ketones (Misra et al, 2005; Nattiv et al, 2007; Smith et al, 1987). Therefore, insufficient energy intake in addition to physical stress may be associated with negative health impacts such as menstrual dysfunction, potentially irreversible bone loss (Sundgot-Borgen & Torstveit, 2003), psychological complications, including depression and low self-esteem, fluid and electrolyte imbalance and impairments in renal, cardiovascular, endocrine, gastrointestinal, immune and thermoregulatory systems (Barrack et al, 2010; Beals & Manore, 1999; Bedford, Prior & Barr, 2010; De Souza & Williams, 2006; Misra et al, 2005; Morgenthal, 2002; Steinman et al, 2003; Vescovi et al, 2008; Wheatley et al, 2012).

MENSTRUAL DISORDERS IN GYMNASTS

In female athletes, low body weight with low dietary energy intake and intense exercise may lead to the development of reproductive abnormalities, such as luteal phase deficiency, primary amenorrhea (delay in the age of menarche), secondary amenorrhea (absence of menstrual cycles lasting more than three months in postmenarchal women) and oligomenorrhea (menstrual cycles occurring at intervals more than 35 days) (Morgenthal, 2002; Nattiv et al, 2007; Otis, 1992).

In bibliography, the prevalence of menstrual disorders estimated in high school athletes in different sports ranges from 18% to 54% (Hoch et al, 2009; Nichols et al, 2006; Thein-Nissenbaum et al, 2011b). In addition, the prevalence of amenorrhea in the athletic population (5%-46%) was above the prevalence found in the general population (2%-5%) (Morgenthal, 2002). Furthermore, it has been noted that the prevalence of menstrual dysfunctions in female athletes engaged in aesthetic sports, such as figure skating, rhythmic sportive gymnastics, artistic gymnastics, diving, synchronized swimming and dance, was higher than in endurance and team/anaerobic athletes (Beals & Manore, 2002). In gymnastics, it has been shown that by the age of 14, only 20% of gymnasts had reached menarche, compared with 40% of distance runners and 95% of the normal population (Bale et al, 1996). A delay in age of menarche (ranging from 14.3 to 16.2 years) is also documented in gymnasts relative to non-athletic females (12 to 13 years) (Baxter-Jones et al, 1994; Beunen, Malina & Thomis, 1999; Claessens, Malina & Lefevre, 1992; Lindholm, Hagenfeldt & Ringertz, 1994; Malina, Bouchard & Bar-Or, 2004; Robinson et al, 1995; Thomis et al, 2005). Besides, it has been suggested that women’s participation in intensive physical training since an early age may lead to delayed age of menarche (Baxter-Jones et al, 1994; Broso & Subrizi, 1996). In the study by Robinson and coworkers (1995), gymnasts exhibited significantly higher prevalence of oligomenorrhea and amenorrhea compared with controls (47% and 0% respectively). Furthermore, it has been estimated that the prevalence of primary amenorrhea is less than 1% in the general population and more than 22% in cheerleading, diving and gymnastics (Beals & Manore, 2002; Chumlea et al, 2003; Nattiv et al, 2007). Similarly, Georgopoulos and coworkers (2002) reported that 35% of the female gymnasts participating in a European championship were amenorrheic although aged over 15 years. All of the above are in line with the observation that participating and competing in sports that emphasize leanness are associated with menstrual dysfunction (Korsten-Reck, 2011; Torstveit & Sundgot-Borgen, 2005c).

The major factors associated with menstrual cycle disturbances in female athletes include energy and nutrient balance, sport modality, performance level, body weight and composition, eating disorders and mental stress. In particular, low energy intake seems to be the most important factor for the induction of menstrual cycle irregularities in athletes (Loucks, Verdu & Heath, 1998). Loucks and coworkers (1998) determined that menstrual disturbances are present only when high stress levels of exercise are combined with low energy availability. Similarly, De Souza and coworkers (2007) noted that menstrual disturbances in exercising women are energy-related and their severity increases in proportion to the magnitude of negative energy balance. In addition, it has been asserted that sports requiring thin bodies, such as gymnastics, tend to have a much higher prevalence of menstrual cycle irregularities and a later age of menarche (Sundgot-Borgen, 1994). Concerning the performance level, it has been found that the better performing athletes tend to have higher prevalence of menstrual irregularities (Schwartz et al, 1981). It has also been suggested that, as adipose tissue serves as an important endocrine organ for the conversion of androgens to oestrogens (Mohamed-Ali, Pinkney & Coppack, 1998), low body fat and eating disorders may play an important causal role in the development of menstrual cycle irregularities in athletes (Frisch, 1984; Sundgot-Borgen, 1998). Besides, research on menstrual disorders indicates that they are usually induced in athletes with low body mass (Trivelli et al, 1995) and low body fat (Theodoropoulou et al, 2005). Finally, it has been said previously that oestrogen production is sensitive to stress (Birch, 2005). Some exercise related stressors are rapid loss of body weight, sudden onset of strenuous exercise, inadequate nutrition to meet energy requirements, psychological and physical stress (Morgenthal, 2002).

Artistic gymnastics is a major sport that requires intensive physical training in combination with a strict control of energy input and a high energy output during childhood and adolescence. Gymnasts are subject to a significant energy drain, occurring early in prepubertal age, and are constantly pressured to achieve low body weight consistent with their sport requirements for a thin somatotype (Georgopoulos et al, 2010). In these weight and body image conscious athletes, reduced energy intake and increased exercise energy expenditure with concomitant low body fat may lead to reduced oestrogen production and primary amenorrhea ((Robinson et al, 1995; Theodoropoulou et al, 2005). Thus, gymnasts tend to develop primary amenorrhea due to training demands (prolonged intensive training, chronic undernutrition, emphasis on leanness) (Yabuuchi et al, 1984). Besides, Weimann (2002) found that young elite female gymnasts displayed low estrogen levels, hypoleptinemia, reduced body fat mass, insufficient caloric intake and retarded menarche.

Female gymnasts, beginning an intense athletic activity at a prepubertal age, being strenuously trained and competing at a high level, are exposed to high levels of physical and psychological stress. Excessive exercise is a stress situation that leads to increased levels of growth hormone, prolactin, glucocorticoids and cathecholamines, together with an elevation of cortisol levels and the Corticotropin Releasing Hormone (CRH) (Mastorakos et al, 2005). These increased hormone levels combined with the chronic stimulation of the hypothalamic-pituitary-adrenal axis under physical and mental stress, in addition to endogenous opioids, melatonin and dopamine can have an inhibitory action on gonadotropin-releasing hormone (GnRH) pulsatility (Keizer & Rogol, 1990). In the female athlete triad, menstrual disorders result from the suppression of the spontaneous pulsatile hypothalamic GnRH secretion, which leads to a decreased pulsatile secretion of luteinizing hormone (LH) and follicle stimulating hormone (FSH) and the prevention of the ovarian stimulation (Gordon, 2010; Williams et al, 1995). LH pulsatility reflects the pulsatile secretion of GnRH from the hypothalamus (Filicori et al, 1998). Dueck & Manore (1996) maintained that high energy expenditure, low energy intake and high psychological and physical stress are the main variables related to negative energy balance (energy drain), which is the primary factor effecting GnRH suppression in female athletes. However, it has been asserted that exercise training has no suppressive effect on LH pulsatility, when dietary energy intake is increased to compensate for exercise energy expenditure (Loucks, Verdu & Heath, 1998). Likewise, Williams and coworkers (1995) suggested that strenuous training may not be a sufficient stimulus to disrupt reproductive hormone secretion unless accompanied by inadequate caloric intake.

As the ovarian hormones are suppressed in amenorrheic athletes, the levels of oestrogen and progesterone fall. Consequences of oestrogen deficiency recorded in athletes include premature loss of bone mineral density (Drinkwater et al, 1984; Morgenthal, 2002; Nichols et al, 2007; Soleimany et al, 2012; Wheatly et al, 2012), impaired endothelial cell function with resultant impaired arterial dilation (Hoch et al, 2003; Lanser et al, 2011; Rickenlund et al, 2005), impaired skeletal muscle oxidative metabolism (Harber, Petersen & Chilibeck, 1998), elevated low-density lipoprotein cholesterol levels (O'Donnell & DeSouza, 2004; Soleimany et al, 2012).

BONE MINERAL DENSITY IN FEMALE GYMNASTS

Although regular weight-bearing exercise has beneficial effects on bone mass, there is evidence that athletes who experience amenorrhea or oligomenorrhea have lower bone mineral density than eumenorrheic athletes (Drinkwater et al, 1984; Drinkwater, Bruemner & Chesnut, 1990; Morgenthal, 2002). Low energy availability may suppress bone formation via effects on hormones that regulate bone formation and facilitate calcium uptake into bone, including oestrogen, insulin, T3, insulin-like growth factor-I, cortisol and leptin (Nattiv et al, 2007). Additionally, since the reproductive hormones affect bone formation and remodelling, any factor that contributes to lower oestrogen levels could influence bone density and predispose female athletes to osteopenia and premature osteoporosis (Morgenthal, 2002; Wheatly et al, 2012). Low oestrogen and progesterone levels in combination with low body weight have been linked to reduced bone mineral density in female athletes (Rencken, Chestnut & Drinkwater, 1996). From the literature, it is clear that eating disorders and low calcium intake combined with menstrual dysfunction and the resultant oestrogens withdrawal are related to loss of bone mineral density, which in turn leads to osteoporosis, increased susceptibility to stress fractures and other musculoskeletal injuries during the competitive years (Drinkwater et al, 1984; Lloyd et al, 1986; Wheatly et al, 2012). In premenopausal women and children, osteoporosis is diagnosed when low bone mineral density is present with other factors, including chronic malnutrition, eating disorders, hypogonadism, glucocorticoid exposure and previous fractures (International Society for Clinical Densitometry, 2004). Amenorrheic athletic women have been found to be strong candidates for bone loss (Snow-Harter, 1994). Recently, another research has showed that female athletes with eating and menstrual disorders may be at greater risk for bone loss, changes in bone mineral density and stress fracture occurrence (Thein-Nissenbaum et al, 2011b). In addition, it has been reported that bone mineral density is inversely related to the age of menarche and it declines as the number of missing menstrual cycles accumulates (Drinkwater, Bruemner & Chesnut, 1990; Morgenthal, 2002). Decreased bone mineral density appears to be generalized throughout the skeleton, in both appendicular and axial skeletal sites (Lebrun, 2006; Morgenthal, 2002; Otis et al, 1997; Rencken, Chestnut & Drinkwater, 1996).

In the literature, it has been observed that college athletes at risk for eating disorders reported menstrual irregularity and suffer from bone injuries more often (Beals & Manore, 2002). Several studies have reported that amenorrheic athletes are at increased risk for stress fractures. Amenorrheic athletes have been found to be two to four times likely to sustain stress factures than eumenorrheic athletes (Bennell et al, 1999). In the study by Thein-Nissenbaum and coworkers (2011b), the cumulative seasonal incidence of musculoskeletal injuries in female high school athletes was reported as 65.6%, but 78.0% in aesthetic athletes aside. Additionally, athletes with eating disorders were twice as likely to sustain a sports-related injury during a sports season (Thein-Nissenbaum et al, 2011b). In a subsequent study, Thein-Nissenbaum and coworkers (2012) estimated a higher prevalence of 71.4% of musculoskeletal injuries in aesthetic female athletes compared with endurance and team/anaerobic athletes (67.5% and 59.6% respectively). Similarly, Beals and Manore (2002) determined that 65.9% of female collegiate athletes reported a muscle injury during their collegiate career, with athletes participating in aesthetic sports exhibiting the highest percentage of self-reported injuries (78.0%), when compared to endurance and team/anaerobic athletes. They concluded that a greater percentage of athletes with irregular menses reported muscle injury (67.4%), as compared to those with eumenorrhea (60.8%). Rauh, Nichols and Barrack (2010) have also observed that female high school athletes who reported menstrual dysfunction were 3 times more likely to incur a musculoskeletal injury than athletes with normal menses.

Nevertheless, it has been established that exercise during growth is associated with site-specific bone mineral accrual (Laing et al, 2005). Furthermore, it has been demonstrated that gymnastics training is associated with greater site-specific bone mass and bone size in retired elite female gymnasts (Eser et al, 2009). Similarly, several studies found that former female gymnasts have greater bone density than sedentary controls at the upper limbs, lower limbs and spine (Bass et al, 1998; Kirchner, Lewis & O'Connor, 1996; Pollock et al, 2006; Scerpella, Dowthwaite & Rosenbaum, 2011; Zanker et al, 2004). In addition, it has been reported that young female oligomenorrheic or amenorrheic athletes in high impact sports may have site-specific beneficial effects on bone mineral density (Slemenda & Johnson, 1993). In gymnastics, female athletes have been shown to exhibit higher bone mineral density than normally active females (Bareither, Grabiner & Troy, 2008; Corujeira et al, 2012; Courteix et al, 1999; Dowthwaite, Rosenbaum & Scerpella, 2012; Helge & Kanstrup, 2002; Laing et al, 2002; Nickols-Richardson & O'Connor, 1999; Vicente-Rodriguez et al, 2007) or female runners at the lumbar spine, hip and whole body, despite a similar prevalence of amenorrhea and oligomenorrhea in athletes (Robinson et al, 1995). It has been suggested that there is a possible protective effect of loading at specific bone sites in athletes with deficient reproductive hormone profile (Eser et al, 2009; Robinson et al, 1995). Specifically, the mechanical forces resulting from increased mechanical loading and strong muscular contraction associated with gymnastics training may have powerful osteogenic effects, which appear to partly compensate for the resorptive effects of low circulating levels of oestrogen. Indeed, gymnasts perform exercises, such as single and double somersaults and dismounts from the uneven bars and balance beam, with a high dynamic impact on the bones, in addition to exercises with a variety of strain (shear, compression, and rotation), which represent important factors in osteogenesis (Helge & Kanstrup, 2002). Thus, the high lean body mass per unit of body surface area in the gymnasts in combination with the production of ground reaction forces of a large magnitude may contribute to enhance bone mineral density (Robinson et al, 1995). Therefore, it may be suggested that bone mineral density is unrelated to menstrual status in female gymnasts.

However, it seems that mechanical loading on the female athlete's skeleton has a beneficial effect on bone mineral density only after resumption of normal menses (Morgenthal, 2002). Notwithstanding there is evidence that weight-bearing exercise in high impact sports, like gymnastics, may selectively protect parts of the skeleton, it cannot offset the detrimental effect of hormonal deficiency (Lebrun, 2006). Besides, the duration of secondary amenorrhoea has been shown to affect the exercise-induced skeletal benefits (Pearce et al, 1996). Furthermore, it has been found that retired gymnasts with a history of either primary or secondary amenorrhoea did not show any benefits in bone density and bone strength in the peripheral skeleton over sedentary controls, in contrast with retired gymnasts without a history of menstrual dysfunction (Ducher et al, 2009). Therefore, adolescent amenorrhoea, which has been associated with a higher incidence of osteoporosis in postmenopausal women (Csermely et al, 2007), may compromise some of the high impact training-induced benefits in cortical and trabecular bone in the peripheral and axial skeleton, hence predisposing the athletes to skeletal fragility later in life (Ducher et al, 2009).

RECOMMENDATIONS FOR PREVENTION AND TREATMENT OF THE GYMNASTS' FEMALE ATHLETE TRIAD

Female athlete triad is a severe health issue concerning especially athletes competing in aesthetic sports, like gymnastics. Prevention and treatment of this syndrome's clinical manifestations are required, in order to maintain athletes' good health and prevent adverse long-term side effects. A collaborative effort among coaches, athletic trainers, parents, health-care providers, a sports nutritionist, a psychologist/psychiatrist and athletes has been recommended to recognize, prevent and treat the female athlete triad (Lanser et al, 2011; Nattiv et al, 2007; Otis et al, 1997; Rooks & Corwell, 2006; Yeager et al, 1993). Social, environmental and personal factors may assist in preventing and reducing the occurrence of the female athlete triad among gymnasts (Nagel, 2003).

Prevention is always preferred over intervention or treatment options and it can be accomplished by thorough risk-factor assessment and screening questions. Prevention usually includes education of athletes, athletic trainers, physical therapists, coaches, other support personnel and parents to raise awareness and effective risk management of the problem and promote healthy nutritional habits and training regimens (Buschman, 2002; Currie & Morse, 2005; Rooks & Corwell, 2006; Tietjen-Smith & Mercer, 2008; Waldrop, 2005). The athletic staff should be informed on signs, symptoms and potential adverse consequences of the condition, in order to assist early recognition and facilitate a healthier approach to athletic performance and competition (Cover, Hanna, Ross & Barnes, 2012; Nagel, 2003; Thein-Nissenbaum et al, 2011b). Since female gymnasts are at risk for developing the female athlete triad showing amenorrhoea, restrained eating behaviour and an increased rate of stress fractures, it has been advised to estimate individual training volume and training capacity at short intervals, in order to avoid negative consequences of high-intensity training (Weimann, 2002). Besides, Corujeira and coworkers (2012) found that, in contrast to high-intense training that reaches 60 hours per week, a moderate weekly training load up to 18 hours is not associated with a compromise of nutritional status, pubertal development and genetically defined height. In their study, competitive gymnastics was associated with an increase in bone mineral density and none of the athletes showed female athlete triad. However, the sample was small and not representative of the gymnasts' population.

The influential role of parents and coaches is also crucial in the treatment of the female athlete triad. In gymnastics, coaches have reported more monitoring/management behaviours towards their athletes, differing from other coaches on their attitudes toward eating and weight in the sport (Heffner et al, 2003). It has been suggested that some of their coaching attitudes and behaviours may inadvertently increase the risk for eating disturbances, if they hold the belief that gymnast's low body weight is beneficial to athletic performance (Heffner et al, 2003; Kerr, Berman & De Souza, 2006). However, coaches are the more suitable persons that could recognize symptoms of chronic energy deficiency, influence athletes' eating behaviour and adopt effective coaching styles and techniques (Wheatly et al, 2012). Therefore, educating them about enhancing the well-being of young gymnasts and developing their athletic talent is very important. Furthermore, the evaluative role of judges concerning technical performance and physicality may be influential on the issues of weight control (Kerr, Berman & De Souza, 2006). It has also been suggested that changes to the competition regulations may stop favoring thinness and reduce the phenomenon of the female athlete triad (Sudi et al, 2004).

It has been established that higher oestrogen levels increase calcium levels, leading to elevated calcium storage in the bone (Drinkwater et al, 1986) and that irregular menses are associated with decreased bone mineral density (Nichols et al, 2007). Thus, early identification and treatment is necessary to protect young amenorrheic athletes from premature osteopenia-osteoporosis. Referral to a physician for examination of the athletes with menstrual irregularity is required (Thein-Nissenbaum et al, 2012), in order to recognize athletes with premature bone loss as early as possible after the onset of amenorrhea, prevent insufficient bone density gain and possibly replace some bone already lost (Morgenthal, 2002).

Negative changes in bone mineral density and cardiovascular biomarkers of female athletes with functional hypothalamic menstrual dysfunction could occur, if proper therapeutic intervention is not considered (Soleimany et al, 2012). Since energy deficiency leads to oestrogen deficiency and consequently insufficient bone density gain, therapeutic intervention of the female athlete triad includes hormone replacement and low energy availability and potential eating disorders treatment, by modifying diet and exercise load in order to improve energy availability and restore normal menstrual cycles (Lanser et al, 2011; Soleimany et al, 2012). However, in treating the female athlete triad, hormone replacement and/or calcium supplementation do not appear to reverse the bone loss in the young athlete (Morgenthal, 2002). In the contrary, increase in body weight and resumption of normal menses with proper nutrition and attention to the physical and psychological pressures are required for bone density recovery (Rackoff & Honig, 2006; Rencken, Chestnut & Drinkwater, 1996). Therefore, it has been suggested that educational efforts encouraging adolescent female athletes improve their caloric intake, to better balance their energy availability and consequently prevent or correct menstrual dysfunction, may help them avoid major musculoskeletal injuries (Thein-Nissenbaum et al, 2012). Although, treatment for eating disorders was found to be insufficient, interrupted or not attempted among athletes (Markser, 2011), it has been reported that when energy availability is restored, menstrual cycles return in approximately 11 months (Casper et al, 2006). Nevertheless, the disruption of the reproductive hormones secretion caused by low energy availability can be restored by refeeding at a very slow rate (Loucks & Verdu, 1998), with the amenorrhoeic females not fully regaining lost bone mineral density, despite returning to a normal reproductive status (Wheatly et al, 2012).

Furthermore, treatment of the female athlete triad includes motivation, communication with the athletes, setting common goals that emphasize the athletes' health and anticipate and prepare them for potential relapse, and development of the necessary skills to maintain behavioural change and a healthy long-term lifestyle (Rooks & Corwell, 2006). Wheatly and co-workers (2012) suggested that along with the education of parents, coaches, educators and health care professionals in identifying and treating females with chronic low energy deficiency, other intervention strategies are also indispensable, such as changing the social milieu, building self-esteem, maintaining a healthy energy balance. Similarly, Lanser and co-workers (2011) maintained that female athletes with eating disorders should receive counselling from a certified sports psychologist to address issues, such as body image issues and self-esteem that may be underlying their problem (Lanser et al, 2011). In addition, a sports dietician should be consulted to evaluate athletes' specific energy requirements (Lanser et al, 2011). An adequate energy intake is crucial to maintain growth and development of tissues and to support energy requirements of young gymnasts. After a relevant assessment and determination of body weight and composition, the athletic personnel should recommend safe weight control strategies (avoiding daily weightings) with a positive health and performance impact (Sudi et al, 2004). Besides, it has been suggested that improved nutrition and weight gain, but not hormone replacement, may reverse large bone density deficits caused in adolescence (Fredericson & Kent, 2005).

CONCLUSION

The female athlete triad is a concerning health condition with adverse long-term side effects. This review article examined the occurrence of the female athlete triad in gymnastics. Gymnastics is a physical activity with high-impact loading activity involving acceleration, deceleration, pushing and pulling movements, acrobatic elements and aesthetically pleasing movements. In addition, it is a sport requiring a strict control of energy consumption and characterized by regular exposure to high-impact prolonged intensive physical training at an early age. Although the mechanical loading on the female gymnast's skeleton has a site- specific beneficial effect on bone mineral density, it cannot offset the detrimental effect of hormonal deficiency on the skeleton caused by low energy availability (increased exercise energy expenditure and/or reduced dietary energy intake). Chronic energy deficiency leads to oestrogen deficiency and consequently loss of bone mineral density.

Low energy availability (with or without eating disorders), menstrual disorders and premature osteoporosis may lead to decreased athletic performance and adverse long-term health consequences. Early diagnosis of the condition in gymnasts is vital for successful intervention and timely treatment to preserve their health and reduce the prevalence of the condition. Adequate screening and development of targeted educational intervention programs have been recommended, in order to facilitate a healthier approach to athletic performance and competition in athletes. A concerted effort among coaches, athletic trainers, parents, athletes, and healthcare personnel is optimal for the recognition, prevention and treatment of the female athlete triad in gymnasts.

REFERENCES

Bachner-Melman, R., Zohar, A.H., Ebstein, R.P., et al. (2006). How anorexic-like are the symptom and personality profiles of aesthetic athletes? *Medicine & Science in Sports & Exercise,* 38, 628–636.

Bale, P., Doust, J., & Dawson, D. (1996). Gymnasts, distance runners, anorexics body composition and menstrual status. *Journal of Sports Medicine & Physical Fitness*, 36(1), 49-53.

Bareither, M.L., Grabiner, M.D., & Troy, K.L. (2008). Habitual site-specific upper extremity loading is associated with increased bone mineral of the ultradistal radius in young women. *Journal of Women's Health*, 17, 1577-1581.

Barrack, M.T., Rauh, M.J, Barkai, H.S., et al. (2008a). Dietary restraint and low bone mass in female adolescent. *American Journal of Clinical Nutrition,* 87, 36–43.

Barrack, M.T., Rauh, M.J., & Nichols, J.F. (2008b). Prevalence and traits associated with low BMD among female adolescent runners. *Medicine & Science in Sports & Exercise,* 40, 2015–2021.

Barrack, M.T., Van Loan, M.D., Rauch, M.J., et al. (2010). Physiologic and behavioral indicators of energy deficiency in female adolescent runners with elevated bone turnover. *American Journal of Clinical Nutrition*, 92, 652–659.

Barrow, G.W., & Saha, S. (1988). Menstrual irregularity and stress fractures in collegiate female distance runners. *American Journal of Sports Medicine,* 16, 209–216.

Bass, S., Pearce, G., Bradney, M., et al. (1998). Exercise before puberty may confer residual benefits in bone density in adulthood: Studies in active prepubertal and retired female gymnasts. *Journal of Bone & Mineral Research,* 13, 500–507.

Baxter-Jones, A.D., Helms, P., Baines-Preece, J., et al. (1994). Menarche in intensively trained gymnasts, swimmers and tennis players. *Annals of Human Biology,* 21, 407–415.

Beals, K.A., & Hill, A.K. (2006). The prevalence of disordered eating, menstrual dysfunction, and low bone mineral density among US collegiate athletes. *International Journal of Sport Nutrition & Exercise Metabolism,* 16, 1–23.

Beals, K.A., & Manore, M.M. (1999). Subclinical eating disorders in physically active women. *Topics in Clinical Nutrition,* 14, 12–29.

Beals, K.A., & Manore, M.M. (2000). Behavioral, psychological, and physical characteristics of female athletes with subclinical eating disorders. *International Journal of Sport Nutrition & Exercise Metabolism,* 10, 128–143

Beals, K.A., & Manore, M.M. (2002). Disorders of the female athlete triad among collegiate athletes. *International Journal of Sport Nutrition & Exercise Metabolism,* 12,281–293.

Bedford, J.L., Prior, J.C., & Barr, S.I. (2010). A prospective exploration of cognitive dietary restraint, subclinical ovulatory disturbances, cortisol, and change in bone density over two years in healthy young women. *Journal of Clinical Endocrinology & Metabolism*, 95, 3291–3299.

Bennell, K., Matheson, G., Meeuwisse, W., et al. (1999). Risk factors for stress fractures. *Sports Medicine,* 28, 91–122.

Beunen, G., Malina, R.M., & Thomis, M. (1999). Physical growth and maturation of female gymnasts. In F.E. Johnston, B., Zemel, & P.B. Eveleth, (Eds), *Human growth in context.* (pp. 281–290). London: Smith-Gordon.

Birch, K. (2005). ABC of sports and exercise medicine: Female athlete triad. *British Medical Journal*, 330, 244–246.

Broso, R., & Subrizi, R. (1996). Gynecologic problems in female athletes. *Minerva Ginecologica*, 48(3), 99-106.

Buschman, B. (2002). Female athlete triad: Education is the key. *ASCM's Certified News,* 12, 1–5.

Byrne, S., & Mclean, N. (2002). Elite athletes: effects of the pressure to be thin. *Journal of Science & Medicine in Sport,* 5, 80–94.

Chan, J.L., & Mantzoros, C.S. (2005). Role of leptin in energy-deprivation: normal human physiology and clinical implications for hypothalamic amenorrhea and anorexia nervosa. *Lancet* 366: 74–85.

Chumlea, W.C., Schubert, C.M., Roche, A.F., et al. (2003). Age at menarche and racial comparisons in US girls. *Pediatrics,* 111, 110–113.

Claessens, A., Lefevre, J., Beunen, G., et al. (1999). The contribution of anthropometric characteristics to performance scores in elite female gymnasts. *Journal of Sports Medicine & Physical Fitness,* 39, 355–360.

Claessens, A.L., Malina, R.M., & Lefevre, J. (1992). Growth and menarchal status of elite female gymnasts. *Medicine & Science in Sports & Exercise*, 24, 755-763.

Cobb, K.L., Bachrach, L.K., Greendale, G., et al. (2003). Disordered eating, menstrual irregularity, and bone mineral density in female runners. *Medicine & Science in Sports & Exercise,* 35, 711–719.

Corujeira S., Santos Silva R, Vieira T., Dias C., Lebre E., Rêgo C. (2012). Gymnastics and the female athlete triad: reality or myth? *Science of Gymnastics Journal,* 4 (3): 5-13.

Cover, K., Hanna, M., Ross, & Barnes, M. (2012). A review and proposed treatment approach for the young athlete at high risk for the female athlete triad. *ICAN: Infant, Child & Adolescent Nutrition,* 4, 21–27.

Courteix, D., Lespessailles, E., Jaffre, C., et al. (1999). Bone mineral acquisition and somatic development in highly trained girl gymnasts. *Acta Paediatrica,* 88, 803-808.

Csermely, T., Halvax, L., Vizer, M., et al. (2007). Relationship between adolescent amenorrhea and climacteric osteoporosis. *Maturitas*, 56, 368–74.

Currie, A., & Morse, E.D. (2005). Eating disorders in athletes: Managing the risks. *Clinical Sports Medicine*, 2, 871–883.

De Souza, M.J., Lee, D.K., VanHeest, J.L., et al. (2007). Severity of energy-related menstrual disturbances increases in proportion to indices of energy conservation in exercising women. *Fertility & Sterility,* 88(4), 971-975.

De Souza, M.J., & Williams, N.I. (2006). Beyond hypooestrogenism in amenorrheic athletes. Energy deficiency as a contributing factor for bone loss. *Current Sports Medicine Reports*, 4, 38–44.

Dowthwaite, J.N., Rosenbaum, P.F., & Scerpella, T.A. (2012). Site-specific advantages in skeletal geometry and strength at the proximal femur and forearm in young female gymnasts. *Bone*, 50(5), 1173-1183.

Drinkwater, B.L., Bruemner, B., & Chesnut III, C.H. (1990). Menstrual history as a determinant of current bone density in young athletes. *Journal of the American Medical Association*, 263, 545–548.

Drinkwater, B.L., Nilson, K., Chesnut III, C.H., et al. (1984). Bone mineral content of amenorrheic and eumenorrheic athletes. *New England Journal of Medicine*, 311, 277-281.

Drinkwater, B.L., Nilson, K., Ott, S., et al. (1986). Bone mineral density after resumption of menses in amenorrheic athletes. *Journal of the American Medical Association*, 256(3), 380-382.

Ducher, G., Eser, P., Hill, B., et al. (2009). History of amenorrhoea compromises some of the exercise-induced benefits in cortical and trabecular bone in the peripheral and axial skeleton: a study in retired elite gymnasts. *Bone*, 45(4), 760-767.

Dueck, C.A., & Manore, M.M. (1996). Role of energy balance in athletic menstrual dysfunction. *International Journal of Sport Nutrition,* 6, 165–190.

Engel, S.G., Johnson, C., Powers, P.S., et al. (2003). Predictors of disordered eating in a sample of elite Division I college athletes. *Eating Behaviors*, 4(4), 333-343.

Erlandson, M.C., Sherar, L.B., Mirwald, R.L., et al. (2007). Growth and maturation of adolescent female gymnasts, swimmers, and tennis players. *Medicine & Science in Sports & Exercise,* 40, 34–42.

Eser, P., Hill, B., Ducher, G., et al. (2009). Skeletal benefits after-long retirement in former elite female gymnasts. *Journal of Bone & Mineral Research,* 24(12), 1981-1988.

Filicori, M., Tabarelli, C., Casadio, P., et al. (1998). Interaction between menstrual cyclicity and gonadotropin pulsatility. *Hormone Research*, 49, 169–172.

Fredericson, M., & Kent, K. (2005). Normalization of bone density in a previously amenorrheic runner with osteoporosis. *Clinical Case Studies,* 37, 1481-1486.

Frisch, R.E. (1984). Body fat, puberty and fertility. *Biological Reviews of the Cambidge Philosophical Society*, 59, 161-88.

Georgopoulos, N., Markou, K., Theodoropoulou, A., et al. (2002). Growth retardation in artistic compared with rhythmic elite female gymnasts. *Journal of Clinical Endocrinology & Metabolism,* 87, 3169–3173.

Georgopoulos, N.A., Roupas, N.D., Theodoropoulou, A., et al. (2010). The influence of intensive physical training on growth and pubertal development in athletes. *Annals of the New York Academy of Sciences*, 1205, 39–44.

Gordon, C.M. (2010). Functional hypothalamic amenorrhea. *New England Journal of Medicine,* 363, 365–371.

Harber, V.J., Petersen, S.R., & Chilibeck, P.D. (1998). Thyroid hormone concentrations and muscle metabolism in amenorrheic and eumenorrheic athletes. *Canadian Journal of Applied Physiology*, 23, 293–306.

Heffner, J.L., Ogles, B.M., Gold, E., et al. **(**2003). Nutrition and eating in female college athletes: A survey of coaches. *Eating Disorders*, 11(3), 209-220.

Helge, E.W., & Kanstrup, I.L. (2002). Bone density in female elite gymnasts: impact of muscle strength and sex hormones. *Medicine & Science in Sports & Exercise*, 34, 174–180.

Herbrich, L., Pfeiffer, E., Lehmkuhl, U., et al. (2011). Anorexia athletica in pre-professional ballet dancers. *Journal of Sports Science,* 11, 1115–1123.

Hoch, A.Z., Dempsey, R.L., Carrera, G.F., et al. (2003). Is there an association between athletic amenorrhea and endothelial cell dysfunction? *Medicine & Science in Sports & Exercise*, 35, 377–383.

Hoch, A.Z., Pajewski, N.M., Moraski, L., et al. (2009). Prevalence of the female athlete triad in high school athletes and sedentary students. *Clinical Journal of Sports Medicine*, 19, 421–428.

Hoch, A.Z., Stavrakos, J.E., & Schimke, J.E. (2007). Prevalence of female athlete triad characteristics in a club triathlon team. *Archives of Physical Medicine and Rehabilitation,* 88, 681–682.

Hulley, A., Currie, A., Njenga, F., et al. (2007). Eating disorders in female distance runners: Effects of nationality and running environment. *Psychology of Sport & Exercise,* 8, 521–533.

International Society for Clinical Densitometry (2004). Writing group for the ISCD position development conference. Diagnosis of osteoporosis in men, women, and children. *Journal of Clinical Densitometry*, 7, 17–16.

Keizer, H.A., & Rogol, A.D. (1990). Physical exercise and menstrual cycle alterations. What are the mechanisms? *Sports Medicine,* 10, 218.

Kerr, G., Berman, E., & De Souza, M.J. (2006). Disordered eating in women's gymnastics: Perspectives of athletes, coaches, parents, and judges. *Journal of Applied Sport Psychology*, 18, 28–43.

Kirchner, E.M., Lewis, R.D., & O'Connor, P.J. (1996). Effect of past gymnastics participation on adult bone mass. *Journal of Applied Physiology,* 80, 226–232.

Korsten-Reck, U. (2011). The female athlete triad. *International SportMed Journal,* 12(4), 156-159.

Krentz, E.M., & Warschburger, P.A. (2011). Longitudinal investigation of sports-related risk factors for disordered eating in aesthetic sports. *Scand Journal Med Sci Sports* doi: 10.1111/j.1600-0838.2011.01380.x.

Laing, E.M., Massoni, J.A., Nickols Richardson, S.M., et al. (2002). A prospective study of bone mass and body composition in female adolescent gymnasts. *Journal of Paediatrics,* 141, 211-216.

Laing, E.M., Wilson, A.R., Modlesky, C.M., et al. (2005). Initial years of recreational artistic gymnastics training improves lumbar spine bone mineral accrual in 4- to 8-year-old females. *Journal of Bone & Mineral Research,* 20, 509–519.

Lanser, E.M, Zach K.N., Hoch A.Z. (2011). The female athlete triad and endothelial dysfunction. *Musculoskeletal Medicine*, 3:458-465.

Lebrun, C. (2006). The female athlete triad. *Women Health Med* 3(3): 119-123.

Lindholm, C., Hagenfeldt, K., & Hagman, U. **(**1995). A nutrition study in juvenile elite gymnasts. *Acta Paediatrica,* 84(3), 273-277.

Lindholm, C., Hagenfeldt, K., & Ringertz, B.-M. (1994). Pubertal development in elite juvenile gymnasts: effects of physical training. *Acta Obstetricia et Gynecologica Scandinavica,* 73, 269-273.

Lloyd, T., Triantafyllou, S.J., Baker, E.R., et al. (1986). Women athletes with menstrual irregularity have increased musculoskeletal injuries. *Medicine & Science in Sports & Exercise,* 18, 374-379.

Loucks, A.B., & Nattiv, A. (2005). The female athlete triad. *Lancet,* 366(Suppl 1), 49-50.

Loucks, A.B., & Verdu, M. (1998). Slow restoration of LH pulsatility by refeeding in energetically disrupted women. *American Journal of Physiology-Regulatory Integrative & Comparative Physiology,* 275, R1218.

Loucks, A.B., Verdu, M., & Heath, E.M. (1998). Low energy availability, not stress of exercise, alters LH pulsatility in exercising women. *Journal of Applied Physiology*, 84(1), 37–46

Malina, R.M., Bouchard, C., & Bar-Or, O. (2004). Growth, maturation, and physical activity. Champaign, Illinois: Human Kinetics.

Markser, V.Z. (2011). Sport psychiatry and psychotherapy. Mental strains and disorders in professional sports. Challenge and answer to societal changes. *European Archives of Psychiatry & Clinical Neurosciences*, 261, S182–S185.

Martinsen, M., Bratland-Sanda, S., Eriksson, A.K., et al. (2010). Dieting to win or to be thin? A study of dieting and disordered eating among adolescent elite athletes and non-athlete controls. *British Journal of Sports Medicine,* 44, 70–76.

Mastorakos, G., Pavlatou, M., Diamanti-Kandarakis, E., et al. (2005). Exercise and the Stress System. *Hormones,* 4, 73–89.

Matejek, N., Weimann, E., Witzel, C., et al. (1999). Hypoleptinaemia in patients with anorexia nervosa and in elite gymnasts with anorexia athletica. *International Journal of Sports Medicine,* 20, 451-456.

McManus, A.M., & Armstrong, N. (2010). Physiology of elite young female athletes. *Medicine & Sport Science,* 56, 23-46.

Misra, M., Miller, K.K., Kuo, K., et al. (2005). Secretory dynamics of leptin in adolescent girls with anorexia nervosa and healthy adolescents. *American Journal of Physiology-Endocrinology & Metabolism,* 289, 373-381.

Mohamed-Ali, V., Pinkney, J.H., & Coppack, S.W. (1998). Adipose tissue as an endocrine and paracrine organ. *International Journal of Obesity & Related Metabolic Disorders,* 22, 1145-1158.

Morgenthal, A.P. (2002). Female athlete triad. *Journal of Chiropractic Medicine,* 1(3), 97-106.

Muscat, A.C., & Long, B.C. (2008). Critical comments about body shape and weight: Disordered eating of female athletes and sport participants. *Journal of Applied Sport Psychology,* 20, 1–24.

Nagel, M. (2003). The relationship of the female athlete triad with psychocognitive functions and balance. *Journal of Exercise Science & Fitness,* 1, 116–124.

Nattiv, A., Loucks, A.B., Manore, M.M., et al. (2007). American College of Sports Medicine Position Stand: The female athlete triad. *Medicine & Science in Sports & Exercise*, 39, 1867–1882.

Nichols, J.F., Rauh, M.J., Barrack, M.T., et al. (2007). Bone mineral density in female high school athletes: Interactions of menstrual function and type of mechanical loading. *Bone,* 41(3), 371-377.

Nichols, J.F., Rauh, M.J., Lawson, M.J., et al. (2006). Prevalence of the female athlete triad syndrome among high school athletes. *Archives of Paediatrics & Adolescent Medicine,* 160, 137–142.

Nickols-Richardson, S.M., O'Connor, P.J., Shapses, S.A., et al. (1999). Longitudinal bone mineral density changes in female child artistic gymnasts. *Journal of Bone & Mineral Research,* 14, 994–1002.

Nickols-Richardson, S.M., Modlesky, C.M., O'Connor, P.J., et al. (2000). Premenarcheal gymnasts possess higher bone mineral density than controls. *Medicine & Science in Sports & Exercise,* 32, 63-69.

O'Donnell, E., & De Souza, M.J. (2004). The cardiovascular effects of chronic hypoestrogenism in amenorrhoeic athletes: A critical review. *Sports Medicine,* 34, 601–627.

Otis, C.L. (1992). Exercise-associated amenorrhea. *Clinical Sports Medicine*, 11, 351–362.

Otis, C.L., Drinkwater, B., Johnson, M., et al. (1997). American College of Sports Medicine position stand. The female athlete triad. *Medicine & Science in Sports & Exercise*, 29, i-ix.

Pearce, G., Bass, S., Young, N., et al. (1996). Does weight-bearing exercise protect against the effects of exercise-induced oligomenorrhea on bone density? *Osteoporosis International,* 6, 448–452.

Petrie, T. (1993). Disordered eating in female collegiate gymnasts: Prevalence and personality/attitudinal correlates. *Journal of Sport & Exercise Psychology,* 15, 424–436.

Petrie, T.A., & Stoever, S. (1993). The incidence of bulimia nervosa and pathogenic weight control behaviors in female collegiate gymnasts. *Research Quarterly for Exercise & Sport*, 64, 238–241.

Pollock, N.K., Laing, E.M., Modlesky, C.M., et al. (2006). Former college artistic gymnasts maintain higher BMD: A nine-year follow-up. *Osteoporosis International,* 17, 1691–1697.

Rackoff, P., & Honig, S. (2006). Anorexia nervosa, athletics, and amenorrhea: the female athlete triad. *Current Opinion Endocrinol, Diabetes & Obesity*, 13(6), 491-496.

Rauh, M.J., Nichols, J.F., & Barrack, M.T. (2010). Relationships among injury and disordered eating, menstrual dysfunction, and low bone mineral density in high school athletes: A prospective study. *Journal of Athletic Training*, 45, 243-252.

Rencken, M.L., Chestnut III, C.H., & Drinkwater, B.L. (1996). Bone density at multiples skeletal sites in amenorrheic athletes. *Journal of the American Medical Association* 276(3): 238–240.

Rickenlund, A., Eriksson, M.J., Schenck-Gustafsson, K., et al. (2005). Amenorrhea in female athletes is associated with endothelial dysfunction and unfavorable lipid profile. *Journal of Clinical Endocrinology & Metabolism,* 90, 1354-1359.

Robinson, T.L., Snow-Harter, C., Taaffe, T.R., et al. (1995). Gymnasts exhibit higher bone mass than runners despite similar prevalence of amenorrhea and oligomenorrhea. *Journal of Bone & Mineral Research,* 10, 26–35.

Rome, E.S., Ammerman, S., Rosen, D.S., et al. (2003). Children and adolescents with eating disorders: the state of the art. *Pediatrics*, 111, 98–108.

Rooks, Y., & Corwell, B.N. (2006). Female athlete triad. *Current Opinion in Orthopaedics,* 17, 149–154.

Rosen, L.W., & Hough, D.O. (1988). Pathogenic weight-control behaviours of female college gymnasts. *Physician & Sportsmedicine,* 16, 141–144.

Sanborn, C.F., Horea, M., Siemers, B.J., & Dieringer, K.I. (2000). Disordered eating and the female athlete triad. *Clinical Sports Medicine*, 19(2), 199–213.

Scerpella, T.A., Dowthwaite, J.N., & Rosenbaum, P.F. (2011). Sustained skeletal benefit from childhood mechanical loading. *Osteoporosis International,* 22(7), 2205-2210.

Schwartz, B., Cumming, D.C., Riordan, E., et al. (1981). Exercise associated amenorrhea: A distinct entity? *American Journal Obstetrics & Gynecology*, 141, 662-670.

Scoffier, S., Maoano, C., & d'Arripe-Loungeville, F. (2010). The effects of social relationships and acceptance on disturbed eating attitudes in elite adolescent female athletes: The mediating role of physical self-conception. *International Journal of Eating Disorders*, 43, 65–71.

Slemenda, C.W., & Johnson, C.C. (1993). High intensity activities in young women: site specific bone mass effects among female figure skaters. *Bone Mineral,* 20, 125-132.

Smith, A., Clemmons, D.R., Underwood, L.E., et al. (1987). The effect of exercise on plasma somatomedin-C/insulinlike growth factor I concentrations. *Metabolism*, 36, 533–537

Smolak, L., Murnen, S., & Ruble, A. (2000). Female athletes and eating problems: A meta-analysis. *International Journal Eat Disorder*, 27, 371–380.

Snow-Harter, C. (1994). Bone health and prevention of osteoporosis in active and athletic women. *Clinical Sports Medicine,* 13, 389–403.

Soleimany, G., Dadgostar, H., Lotfian, S., et al. (2012). Bone mineral changes and cardiovascular effects among female athletes with chronic menstrual dysfunction. *Asian Journal of Sports Medicine,* 3(1), 53-58.

Steinman, L., Conlon, P., Maki, R., et al. (2003). The intricate interplay among body weight, stress, and the autoimmune response to friend or foe. *Journal of Clinical Investigation*, 111, 183-185.

Sudi, K., Ottl, K., Payerl, D., et al. (2004). Anorexia athletica. *Nutrition,* 20(7-8), 657-661.

Sundgot-Borgen, J. (1994). Risk and trigger factors for the development of eating disorders in female elite athletes. *Medicine & Science in Sports & Exercise,* 26(4), 414–419.

Sundgot-Borgen, J. (1998). The triad of eating disorders, amenorrhea and osteoporosis. *Isostar Sport Nutrition Foundation,* 7, 3-8.

Sundgot-Borgen, J., & Torstveit, M.K. (2003). The female athlete triad- the role of nutrition. *Schweizerische Zeitschrift fur Sportmedizin und Sporttraumatologie,* 51, 47–52.

Sundgot-Borgen, J., & Torstveit, M.K. (2004). Prevalence of eating disorders in elite athletes is higher than in the general population. *Clinical Journal of Sport Medicine,* 14, 25–32.

Thein-Nissenbaum, J.M., & Carr, K.E. (2011a). Female athlete triad syndrome in the high school athlete. *Physical Therapy in Sport*, 12(3), 108-116.

Thein-Nissenbaum, J.M., Rauh, M.J., Carr, K.E., et al. (2011b). Associations between disordered eating, menstrual dysfunction, and musculoskeletal injury among high school athletes. *Journal of Orthopaedic & Sports Physical Therapy,* 41(2), 60-69.

Thein-Nissenbaum, J.M., Rauh, M.J., Carr, K.E., et al. (2012). Menstrual irregularity and musculoskeletal injury in female high school athletes. *Journal of Athletic Training*, 47(1), 74-82.

Theodoropoulou, A., Markou, K.B., Vagenakis, G.A., et al. (2005). Delayed but normally progressed puberty is more pronounced in artistic compared with rhythmic elite gymnasts due to the intensity of training. *Journal of Clinical Endocrinology & Metabolism,* 90(11), 6022-6027.

Thomis, M., Claessens, A., Lefevre, J., et al. (2005). Adolescent growth spurts in female gymnasts. *Journal of Pediatrics,* 146, 239-244.

Tietjen-Smith, T., Mercer, J. (2008). The female athlete triad: A statement of the problem. *Journal of Sports and Recreation,* 2, 1–6.

Torstveit, M.K., & Sundgot-Borgen, J. (2005a). The female athlete triad: Are elite athletes at increased risk? *Medicine & Science in Sports & Exercise,* 37, 184-193.

Torstveit, M.K., & Sundgot-Borgen, J. (2005b). The female athlete triad exists in both elite athletes and controls. *Medicine & Science in Sports & Exercise,* 37, 1449–1459.

Torstveit, M.K., & Sundgot-Borgen, J. (2005c). Participation in leanness sports but not training volume is associated with menstrual dysfunction: A national survey of 1276 elite athletes and controls. *British Journal of Sports Medicine,* 39, 141-147.

Torstveit, M.K., Rosenvinge, J.H., & Sundgot-Borgen, J. (2008). Prevalence of eating disorders and the predictive power of risk models in female elite athletes: a controlled study. *Scandinavian Journal of Medicine & Science in Sports*, 18(1), 108-118.

Trivelli, M.R., Biglia, C., Castagno, A., et al. (1995). Sports and adolescence: the effect of competitive athletics on menstrual function. *Minerva Ginecologica,* 47(4), 133-141.

Van den Berg, P., Wertheim, E., Thompson, J., et al. (2002). Development of body image, eating disturbance and general psychological functioning in adolescent females: A replication using covariance structure modeling in an Australian sample. *International Journal of Eating Disorders*, 32, 46–51.

Vescovi, J.D., Scheid, J.L., Hontscharuk, R., et al. (2008). Cognitive dietary restraint: Impact on bone, menstrual and metabolic status in young women. *Physiology & Behavior,* 95, 48–55.

Vicente-Rodriguez, G., Dorado, C., Ara, I., et al. (2007). Artistic versus rhythmic gymnastics: effects on bone and muscle mass in young girls. *International Journal of Sports Medicine,* 28, 386-393.

Waldrop, J. (2005). Early Identification and Intervention for Female Athlete triad. *Journal of Paediatric Health Care,* 19(4), 213-220.

Weimann, E. (2002). Gender-related differences in elite gymnasts: the female athlete triad. *Journal of Applied Physiology*, 92(5), 2146-2152.

Wheatley, S., Khan, S., Szekely, A.D., et al. (2012). Expanding the Female Athlete Triad concept to address a public health issue. *Performance Enhancement & Health*, 1(1), 10-27.

Williams, M. (1984). Oligomenorrhoea and amenorrhoea associated with exercise. A literature review. *Australian Family Physician*, 13(9), 659-663.

Williams, N.L., & Young JC. (1995). Strenuous exercise with caloric restriction: effect on luteinizing hormone secretion. *Medicine & Science in Sports & Exercise*, 27(10), 1390–1398.

Yabuuchi, F., Ichikawa, Y., Arakawa, M., et al. (1984). The influence of strenuous muscle stimulation on the menarche. *Journal of UOEH*, 6(1), 47-55.

Yeager, K.K., Agostini, R., Nattiv, A., et al. (1993). The female athlete triad: disordered eating, amenorrhea, osteoporosis. *Medicine & Science in Sports & Exercise*, 25, 775–777.

Zach, K.N., Smith, A.L., & Hoch, A.Z. (2011). Advances in management of the female athlete triad and eating disorders. *Clinical Sports Medicine*, 30, 551–573.

Zanker, C.L., Osborne, C., Cooke, C.B., et al. (2004). Bone density, body composition and menstrual history of sedentary female former gymnasts, aged 20-32 years. *Osteoporosis International*, 15, 145–154.

Corresponding author:

Theofanis Siatras
Department of Physical Education and Sport Sciences,
Aristotle University of Thessaloniki, 54124,
Thessaloniki, Greece
Tel/Fax: 0032310992179
E-mail: fsiatras@phed.auth.gr