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Eating Disorders in Athletes: The Female Athlete Triad and RED-S - A Literature Review

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Abstract

Athletes, particularly females involved in aesthetic or endurance sports, are at increased risk for developing eating disorders (EDs), which are frequently linked to low energy availability (LEA). LEA, whether intentional or unintentional, disrupts physiological systems and underlies both the Female Athlete Triad and the broader concept of Relative Energy Deficiency in Sport (RED-S). This review examines the prevalence, diagnostic approaches, health consequences, and treatment strategies for EDs in athletic populations. The physiological consequences of LEA include hormonal imbalances, menstrual dysfunction, impaired bone mineral density (BMD), cardiovascular abnormalities, and reduced metabolic and immune function. Psychological factors such as perfectionism, body dissatisfaction, and stress susceptibility are both contributors to and consequences of LEA-related disorders. These issues significantly compromise athletic performance by impairing recovery, increasing injury risk, and limiting training adaptations. Prevention strategies emphasize early education, targeted screening, and programs like ATHENA, which promote healthy behaviors and body image among adolescent athletes. Treatment focuses on restoring adequate energy availability through nutritional and

behavioral adjustments, with pharmacological intervention considered only in select cases. Multidisciplinary support is essential for effective management and long-term recovery.

Methods and Materials

This literature review was conducted using scientific articles retrieved from the PubMed database. Relevant studies published in English were selected based on their focus on eating disorders, low energy availability, the Female Athlete Triad, and Relative Energy Deficiency in Sport (RED-S) in athletic populations. Preference was given to recent publications, systematic reviews, and original research articles. The gathered literature was critically analyzed to provide a comprehensive overview of current knowledge on the topic.

Keywords: Female Athlete Triad, Relative Energy Deficiency in Sport, RED-S, Low Energy Availability, LEA, Eating Disorders, Disordered Eating, Athletes' Health

Introduction

Eating disorders (EDs) are severe psychiatric conditions often linked to significant medical complications and elevated mortality rates [1]. Athletes may be particularly vulnerable to developing EDs due to the combination of intense physical training and psychological pressures inherent in competitive sport. These pressures often stem not only from internal expectations but also from external sources such as coaches, teammates, and the broader sporting culture, which may promote a specific body type perceived as optimal for performance or aesthetics [2]. Engaging in physical activity and exercise offers many health advantages, particularly when the body receives adequate energy to support both training and daily functions. When energy intake falls short of meeting these demands, a condition known as Low Energy Availability (LEA) may occur. LEA arises when dietary energy consumption is insufficient in relation to the energy expended through exercise and normal physiological processes. It can stem from behaviors such as compulsive exercise, poorly informed dietary choices, or restrictive eating patterns. While LEA can be the result of deliberate attempts to modify body composition, it may also develop unintentionally—for instance, through structured yet misinformed efforts to meet sport-specific physique standards, or simply by failing to adjust energy intake in response to increased training demands. When sustained, LEA can disrupt several physiological systems, affecting menstrual health, bone density, metabolic rate, immune function, and cardiovascular performance [3].

Building on the concept of low energy availability, the Female Athlete Triad was originally described as a combination of three interrelated conditions: reduced energy intake (with or without an eating disorder), menstrual irregularities—most notably secondary amenorrhea—

and decreased bone mineral density [4]. More recently, however, the International Olympic Committee has broadened this framework by introducing the term Relative Energy Deficiency in Sport (RED-S). This updated model reflects a wider range of physiological and psychological consequences stemming from LEA and highlights that these issues can affect not only female athletes, but also their male counterparts [5].

The aim of this paper is to provide a comprehensive review of current knowledge regarding the prevalence, diagnostic criteria, health consequences, and evidence-based strategies for the prevention and treatment of eating disorders among athletes.

Epidemiology

The probability of developing eating disorders in athletic populations is influenced by variables like gender, the specific sport practiced, and whether the athlete competes recreationally or professionally [6].

Global estimates suggest that eating disorders affect approximately 8.4% of women and 2.2% of men, with rates steadily rising. Certain populations, including athletes, appear to be particularly vulnerable. Although numerous studies have examined whether athletes are more susceptible to eating disorders than the general public, findings remain inconsistent [7]. Some research, including a meta-analysis of 34 studies, indicates a heightened risk of disordered eating behaviors among athletes [8]. More recent large-scale data support this, showing greater prevalence of both diagnosed and subclinical eating disorders in athletes compared to non-athletes [9].

Conversely, other findings suggest that regular involvement in sport—especially at a non-elite level—might serve as a protective factor, potentially due to the negative impact disordered eating can have on performance [10]. However, this protective effect was not observed among elite-level athletes. While regular physical activity is generally associated with improved mental health, excessive exercise, particularly at the level seen in professional sport, may contribute to adverse outcomes, including the onset of disordered eating patterns. Compulsive or maladaptive exercise behaviors have been identified as significant contributors to the development of eating disorders [7].

In sports where appearance or leanness is emphasized—commonly referred to as "aesthetic" or "lean" sports (e.g., gymnastics, ballet, figure skating, rowing, diving, and long-distance running)—athletes are frequently expected to maintain a low body weight or slim physique. This contrasts with "non-aesthetic" or "non-lean" sports, such as team ball sports (e.g., soccer, volleyball) and power-based disciplines (e.g., shot put), where physical appearance is less central to performance. Athletes in aesthetic or lean sports face a higher risk of disordered eating

behaviors and ED-related psychological symptoms due to the belief that body weight and shape are critical to athletic success. These sport-specific ideals can lead to unhealthy patterns, including excessive training and disordered eating behaviors like food restriction or purging, in attempts to modify physique and enhance performance [2].

Clinical Presentation and Diagnosis

The Female Athlete Triad refers to a combination of three interrelated conditions commonly observed in athletes: low energy availability (LEA), disrupted menstrual function, and reduced bone mineral density. Over time, it became clear that these components may not always be simultaneously present, and their manifestation can vary widely depending on the type of sport, increasing the risk of underdiagnosis. In response to this limitation, the International Olympic Committee (IOC) introduced the broader concept of Relative Energy Deficiency in Sport (RED-S) in 2014. This updated framework emphasizes that inadequate energy availability can disrupt a wide range of physiological systems beyond reproductive and skeletal health. RED-S can impair metabolic, endocrine, cardiovascular, gastrointestinal, immune, and hematologic functions, ultimately affecting both performance and overall health.

LEA results from either insufficient caloric intake or excessive energy expenditure, prompting the body to adapt by prioritizing essential functions (e.g., survival) over less critical ones, such as growth and reproduction. Energy availability (EA) is typically estimated by subtracting exercise energy expenditure from dietary intake, then dividing by fat-free mass (in kg). Although EA is a theoretical construct and difficult to assess in routine practice, understanding its role is crucial in athlete health assessment. Optimal EA is considered to be over 45 kcal/kg of fat-free mass per day, while levels below 30 kcal/kg are strongly associated with physiological adaptations that can negatively impact health [11].

Diagnosing RED-S does not rely on specific lab results but rather involves identifying athletes at risk due to insufficient energy availability. This requires a thorough medical history, including questions about diet, training, menstrual patterns, stress, and mood, as well as personal and family history of eating or reproductive disorders. Psychosocial factors like perfectionism and the desire for social approval should also be assessed, especially in cases of amenorrhea [11].

Recently, various screening tools have been developed to detect symptoms of low energy availability (EA) in athletes, particularly by assessing physiological signs linked to the Female Athlete Triad and RED-S. One such tool is the Low Energy Availability in Females Questionnaire (LEAF-Q). Current literature suggests that individualized clinical evaluations—based on diagnostic criteria for the Triad, LEAF-Q responses, and the RED-S Clinical Assessment Tool (RED-S CAT)—are essential for effective screening [12].

Functional hypothalamic amenorrhea—marked by menstrual disturbances due to hormonal suppression in the absence of structural disease—is a frequent early sign of RED-S. It is a diagnosis of exclusion, requiring the elimination of other causes such as thyroid dysfunction, tumors, or congenital anomalies [11].

Assessment includes a physical exam, hormonal testing (e.g., FSH, LH, estradiol, prolactin, TSH), and, when indicated, additional tests based on clinical suspicion (e.g., inflammatory markers, androgens, metabolic panel). Bone mineral density (BMD) testing is recommended in cases of prolonged menstrual dysfunction, low BMI, significant weight loss, or known eating disorders. Z-scores, rather than T-scores, are preferred for interpretation in adolescents and young athletes. Low BMD is defined by a Z-score between –1 and –1.9 in the presence of risk factors, while osteoporosis is diagnosed when the Z-score is below –2 with accompanying risks [11].

Health and Performance Consequences

Endocrine Effects

Low energy availability has a significant impact on the reproductive system and related hormonal functions. Both male and female athletes with low EA typically exhibit reduced body mass index (BMI), fat mass, and resting metabolic rate (RMR) compared to those with sufficient energy availability [13].

Hormonal responses to low EA vary. Levels of leptin—a hormone that suppresses appetite—are reduced in both sexes [13, 14], while adiponectin tends to increase in some women, though its patterns in men remain inconsistent and under-researched. Ghrelin, an appetite-stimulating hormone, is elevated in women with low EA [13, 14] but remains unchanged in men. Peptide YY (PYY), which also suppresses appetite, increases in both genders under low EA conditions. Oxytocin levels are generally lower in athletes than in non-athletic controls, though its specific role in energy balance and behavior remains unclear. Insulin, a key regulator of glucose metabolism, is decreased in energy-deficient athletes of both sexes, whereas its co-secreted hormone, amylin, has yet to be studied in this context. Additionally, levels of IGF-1 (total and bioavailable) are lower in both male and female athletes with low EA. In women, thyroid hormone T3 is consistently reduced; in men, lower TSH:T3 ratios have been observed. These thyroid markers may be useful in monitoring athletes at risk for RED-S. Although cortisol is often elevated in low EA states, this is not always the case, as cortisol also rises in response to general physical and psychological stress, including exercise. Reproductive hormone levels are also affected. Estradiol and progesterone are consistently low in women with insufficient energy availability, aligning with the model of functional hypothalamic amenorrhea (FHA). Among

male athletes, findings regarding testosterone levels are mixed, possibly due to variations in study design and duration of energy deficiency [13].

Reproductive Dysfunction

Menstrual disturbances are frequently observed in female athletes, with reported prevalence ranging from 1% to as high as 64%. These disturbances include a spectrum of conditions such as primary amenorrhea (no menarche by a certain age), oligomenorrhea (infrequent cycles >35 days), anovulation, secondary amenorrhea (absence of menstruation for ≥3 months), and luteal phase defects. Diagnosing subtle disruptions like anovulation or luteal phase dysfunction can be challenging, as regular cycle length may still occur. These menstrual irregularities are typically due to functional hypothalamic amenorrhea (FHA), caused by energy deficiency that disrupts normal GnRH and LH pulsatility. Notably, changes in LH secretion can occur within just a few days of energy availability dropping below 30 kcal/kg of fat-free mass. Research has shown a dose-dependent relationship between the degree of energy deficiency and the likelihood of menstrual dysfunction [15, 16].

FHA is believed to result from the interaction of multiple physiological pathways triggered by LEA. Elevated levels of cortisol and corticotropin-releasing hormone (CRH) due to stress, along with decreased levels of leptin, have been shown to suppress GnRH secretion. This hormonal cascade impairs folliculogenesis and ovulatory function, ultimately leading to reduced concentrations of estradiol and progesterone [11].

Importantly, menstrual irregularities are closely linked to reduced bone mineral density (BMD) [17]. Athletes with amenorrhea or oligomenorrhea tend to have lower BMD compared to those with normal cycles and face an elevated risk of bone stress injuries [18]. In adolescent athletes, the longer the duration of amenorrhea, the greater the reduction in bone density [17]. Additionally, female collegiate runners with disrupted menstrual cycles are more prone to severe stress fractures and show negative alterations in bone microarchitecture and structural integrity [15, 19].

A recent review highlighted that the neuroendocrine responses to low energy availability (LEA) in male athletes remain insufficiently explored. Although the underlying mechanisms are not yet fully clarified, evidence suggests that men engaged in intense training may experience reductions in testosterone levels, along with symptoms consistent with a hypogonadal state. Furthermore, higher training volume and intensity—particularly in endurance sports—have been linked to decreased libido. These hormonal alterations may carry important health consequences for men, including potential impacts on fertility, bone density, and metabolic regulation [20].

Bone health

Low energy availability (LEA) has a detrimental impact on bone development by reducing key hormonal regulators involved in bone metabolism. These include estrogens, which help inhibit bone resorption and stimulate osteoblast activity; IGF-1, which supports the formation of new bone tissue; leptin, involved in osteoblast proliferation; and triiodothyronine (T3), which also promotes bone formation. As a result, both bone formation and turnover are suppressed, impairing the body's natural ability to repair skeletal microdamage and thereby increasing the risk of fractures [11].

While weight-bearing exercise is generally recognized for its positive effect on bone mineral density (BMD), recent research suggests that female endurance athletes—particularly those at the elite level—are still at notable risk for poor bone health. Studies have reported that up to 41–45% of elite endurance athletes present with low BMD. In contrast, sports that involve high-impact or irregular loading patterns, such as gymnastics, volleyball, soccer, and racquet sports, tend to have more favorable outcomes for bone strength and density [15].

Engagement in these types of impact-loading sports during early puberty is associated with achieving higher peak bone mass, and continued participation into late adolescence and adulthood helps preserve these gains. Since the most rapid bone accrual typically occurs between the ages of 10 and 14, and peak bone mass is usually achieved by the third decade of life, early identification and management of bone disorders in young athletes is essential. Timely intervention during these critical developmental years can significantly influence long-term skeletal health and reduce the risk of bone-related injuries [15].

Although research is still limited, emerging evidence indicates that male athletes with low energy availability may be at risk for reduced bone mineral density and a higher likelihood of injuries. Those engaged in endurance disciplines tend to show lower BMD, body weight relative to expectations, and BMI compared to peers involved in strength-based or team sports. Key risk factors associated with decreased BMD in male athletes include low body weight and high weekly running volume. Cross-sectional studies have consistently reported that male endurance athletes—particularly runners and cyclists—are more prone to insufficient energy intake and lower reproductive hormone levels. Additionally, adolescent boys diagnosed with anorexia nervosa have been shown to exhibit significantly reduced BMD in the femoral neck, hip, spine, and across the whole skeleton compared to healthy controls [15].

Cardiovascular Consequences

Low energy availability (LEA) can negatively impact the cardiovascular system. Changes in lipid profiles, such as elevated levels of cholesterol, low- and high-density lipoproteins, and

triglyceride, have been observed. Vascular health may also be compromised, as LEA has been linked to endothelial dysfunction and increased vascular resistance, often in conjunction with higher central fat accumulation. Athletes with amenorrhea may exhibit lower resting heart rates and systolic blood pressure, likely due to altered regulation of the renin-angiotensin-aldosterone system. In more advanced cases of LEA, more serious cardiovascular complications can develop, including abnormally slow heart rate, low blood pressure, structural heart abnormalities, pericardial fluid accumulation, and irregular heart rhythms [11].

Psychological Consequences

Psychological challenges can either precede or emerge as a result of Relative Energy Deficiency in Sport (RED-S). Disordered eating frequently co-occurs with various mental health issues and appears to be more prevalent among adolescent elite athletes compared to their non-athletic peers. Research suggests that specific personality traits common in competitive athletes may elevate the risk of such behaviors [21]. Adolescent girls experiencing functional hypothalamic amenorrhea (FHA) often show signs of low mood, psychosomatic symptoms, poor stress resilience, social discomfort, body image dissatisfaction, and weight-related anxiety. These psychological patterns are closely aligned with those observed in youth diagnosed with clinical eating disorders. Therefore, when evaluating RED-S, it is essential that psychological aspects are thoroughly considered and managed as part of a coordinated, multidisciplinary care approach [22].

Performance Consequences

The combined physiological and psychological effects of low energy availability can hinder athletic performance by prolonging recovery, limiting training adaptations, and increasing the likelihood of missed training sessions due to injury or illness [22].

A recent study investigating female athletes aged 15 to 30 found a clear association between low energy availability (LEA) and reduced athletic performance. Athletes with LEA reported decreased responsiveness to training, impaired concentration and coordination, poor decision-making, increased irritability and mood disturbances, as well as lower endurance capacity. These findings reinforce the concept that insufficient energy intake can significantly compromise sport-specific performance outcomes, as outlined in the RED-S framework established by the International Olympic Committee [23].

A retrospective cohort study involving over 300 high school female athletes found a strong link between disordered eating (DE) and increased injury risk during the competitive season. Over one-third of participants reported disordered eating behaviors, and those athletes were more than twice as likely to experience musculoskeletal injuries compared to their peers with normal

eating habits. The study also confirmed that a history of DE or previous injury significantly increased the likelihood of sustaining a new injury. These findings suggest that energy-related disturbances—particularly those involving disordered eating—can negatively impact physical resilience and increase time lost from training and competition due to injury [24].

Prevention

Primary prevention aims to stop the development of eating disorders before they occur by targeting known risk factors and promoting protective behaviors. This approach is most effective when directed at high-risk groups—such as adolescent athletes in weight-sensitive or aesthetic sports—and should begin early, ideally between the ages of 9 and 11. Core strategies include integrating nutrition and body image education into athlete and coach training, discouraging extreme dieting, and fostering healthy attitudes toward food, performance, and body composition. Educational efforts can involve seminars, printed materials, or digital resources, and should also extend to coaches, health professionals, and sports governing bodies. Modifications to sport-specific rules and judging criteria, especially in disciplines that reward leanness, are also recommended [25].

Secondary prevention focuses on the early detection of athletes at risk. This includes the use of self-assessment questionnaires, although disclosure may be limited due to fear of exclusion from competition. To increase reliability, anonymity and confidentiality should be ensured. Secondary prevention also involves identifying sport-specific risk factors, which vary by discipline, sex, and cultural context. More robust longitudinal research is needed to understand these risk profiles and to validate early intervention strategies [25].

An example of a structured prevention effort is the ATHENA program (Athletes Targeting Healthy Exercise & Nutrition Alternatives), designed specifically for high school female athletes. The program was developed as a team-centered initiative aimed at promoting health and preventing risky behaviors among high school-aged female athletes. Its primary focus was to reduce the risk of disordered eating, substance use for body modification, and general substance abuse by fostering life skills, improving nutritional awareness, and challenging unrealistic body image ideals perpetuated by media [26].

Initial results following the program indicated a decline in the intake of diet pills and appearance- or performance-enhancing substances, along with improvements in diet-related knowledge and body image perception. However, no immediate changes were noted in alcohol, cannabis, or tobacco use. Long-term evaluation, conducted one to three years after participants had completed high school, revealed more substantial behavioral shifts. Former ATHENA participants reported reduced consumption of alcohol, cannabis, and cigarettes compared to

their non-participating peers. They also displayed a better understanding of calcium requirements and tended to prefer body shapes reflecting more realistic and health-conscious standards. These outcomes suggest that the program's peer-driven format and focus on developing psychosocial competencies contributed to its sustained effectiveness beyond the intervention period [26].

Treatment

The primary focus of treatment is restoring sufficient energy availability (EA) as early as possible to prevent complications such as menstrual dysfunction, reduced bone density, and eating disorders. Increasing EA—through higher caloric intake, reduced energy expenditure, or both—can lead to the return of menstruation, improved bone health, and better vascular function. Successful treatment usually requires collaboration among various healthcare professionals, such as medical doctors, nutrition specialists, athletic support staff, and, if needed, mental health experts. Additionally, involvement from coaches and family members can provide valuable support throughout the recovery process. In practice, increasing daily intake by 200–600 kcal, aiming for 20–30% above baseline needs, can help raise EA when precise measurements aren't possible. Whole foods are preferred over supplements. While improvements in weight and menstruation may be seen with EA above 30 kcal/kg FFM/day, optimal bone recovery may require levels above 45 kcal/kg. Even with optimal intake, menstrual function may take 6 to 12 months to normalize [15].

Maintaining optimal intake of key micronutrients is crucial for athletic health, particularly for supporting bone mineral density (BMD). Vitamin D supports bone health, immune response, and recovery. Its deficiency impairs calcium and phosphorus absorption and increases injury risk. Supplementation (e.g., 800–4000 IU) can reduce fracture rates, especially when dietary intake is low or sun exposure is insufficient. Calcium is critical for bone strength. Athletes, especially those with menstrual disturbances or low energy availability (LEA), may need up to 1500 mg/day. Intake should be spread throughout the day due to limited absorption per dose. Phosphorus contributes to energy production (e.g., ATP) and muscle contraction but must remain balanced with calcium to avoid hormonal disruption. Magnesium supports oxygen transport, electrolyte homeostasis, and metabolism. Athletic needs may be up to 20% higher than in the general population. Deficiency can impair endurance and increase oxidative stress. Iron is frequently deficient in female athletes, particularly vegetarians and endurance runners. Low levels reduce performance. Dietary sources like red meat provide the most absorbable form. Supplementation is often necessary in high-risk individuals [4].

Pharmacological intervention may be appropriate in some cases, particularly when menstrual function has not returned after 6–12 months of consistent nonpharmacological treatment and there is evidence of decreased bone mineral density (BMD). Although combined oral contraceptives (COCs) are commonly used to regulate menstrual cycles in athletes with menstrual irregularities, their use for this purpose is not advised. COCs can mask natural recovery and offer a false sense of improvement, and studies show they are ineffective in improving BMD due to their suppression of IGF-1 via hepatic metabolism. If hormonal therapy is deemed necessary, the preferred option is transdermal estradiol combined with cyclic oral progestin, which supports bone health without suppressing IGF-1 [11].

Conclusion

Eating disorders in athletes—particularly in the context of the Female Athlete Triad and RED-S—present a serious challenge to both physical health and athletic performance. The underlying issue of low energy availability can affect numerous physiological systems, including reproductive, endocrine, cardiovascular, and skeletal health, while also contributing to psychological distress and reduced sport-specific capacity. Early detection and prevention are crucial, especially among young athletes in sports that emphasize leanness or aesthetic appearance. Comprehensive educational initiatives, early screening, and the involvement of multidisciplinary teams are key to reducing risk and promoting recovery. Treatment should prioritize restoring energy availability through individualized nutritional and behavioral strategies, with pharmacological options used only when necessary. Ultimately, protecting athlete health requires collaboration between athletes, coaches, healthcare providers, and sport organizations to foster an environment that values both performance and well-being.

Disclosure

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