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Relative Energy Deficiency in Sport (RED-S) - a consequence of the pursuit of perfection - a literature review

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Abstract

Introduction and purpose: Relative Energy Deficiency in Sport (RED-S) is a multifactorial syndrome that negatively affects a wide range of physiological and psychological functions in athletes. It is often linked to high training loads, inadequate nutrition, and pressures related to performance and body composition. The pursuit of perfection in sport can encourage behaviors such as excessive training and restrictive eating, which increase the risk of developing RED-S. The purpose of this review is to summarize current knowledge on the causes, risks, and consequences of RED-S in athletes. It also aims to provide guidance for effective prevention and management strategies.

State of knowledge: RED-S arises when athletes' energy intake does not meet the demands of training and basic bodily functions, leading to disruptions in endocrine, metabolic, bone, and immune health, as well as mental well-being. It can affect both male and female athletes across a variety of sports, not only those emphasizing leanness. The condition can impair performance, slow recovery, and increase the risk of injuries. Growing awareness of RED-S has led to improvements in screening, diagnosis, and management practices within sports and clinical settings.

Conclusions: Despite being motivated by high performance aspirations, striving for an ideal body composition or optimal performance can increase the risk of developing RED-S, which may lead to serious health consequences. Increasing awareness can help promote preventive measures and improve health among the athlete population.

Key words: Relative Energy Deficiency in Sport, Female Athlete Triad Syndrome, Feeding and Eating Disorders, Athletes.

1. Introduction

Relative Energy Deficiency in Sport (RED-S) is a complex set of symptoms caused by low energy availability (LEA), which results from a disparity in the amount of caloric intake (diet) and caloric expenditure (exercise) in an athlete, resulting in insufficient energy to maintain the functions necessary for optimal health and performance [1, 2]. It leads to physiological and/or

psychological dysfunction, which negatively affects health and performance [3, 4]. RED-S may be associated with disturbances in metabolic rate, immunity, cardiovascular health, skeletal health, protein synthesis and menstruation, amongst others [1]. LEA may affect athletes competing across any sports discipline, however, certain sports may be associated with a higher risk [5].

RED-S syndrome evolved from the condition which was formerly referred to as the Female Athlete Triad [6]. This triad includes, in addition to LEA, impaired bone mineral density (BMD) and dysregulation of the menstrual cycle [7]. The introduction of the RED-S syndrome was intended to highlight the complexity of the problem and emphasize that it can also affect male athletes [4].

In 2023, the International Olympic Committee updated the definition of RED-S and described it as: a syndrome of impaired physiological and/or psychological functioning experienced by female and male athletes that is caused by exposure to problematic (prolonged and/or severe) low energy availability. The detrimental outcomes include, but are not limited to, decreases in energy metabolism, reproductive function, musculoskeletal health, immunity, glycogen synthesis and cardiovascular and haematological health, which can all individually and synergistically lead to impaired well-being, increased injury risk and decreased sports performance [8]. The history of the development of concepts and their definitions is presented in Figure 1.

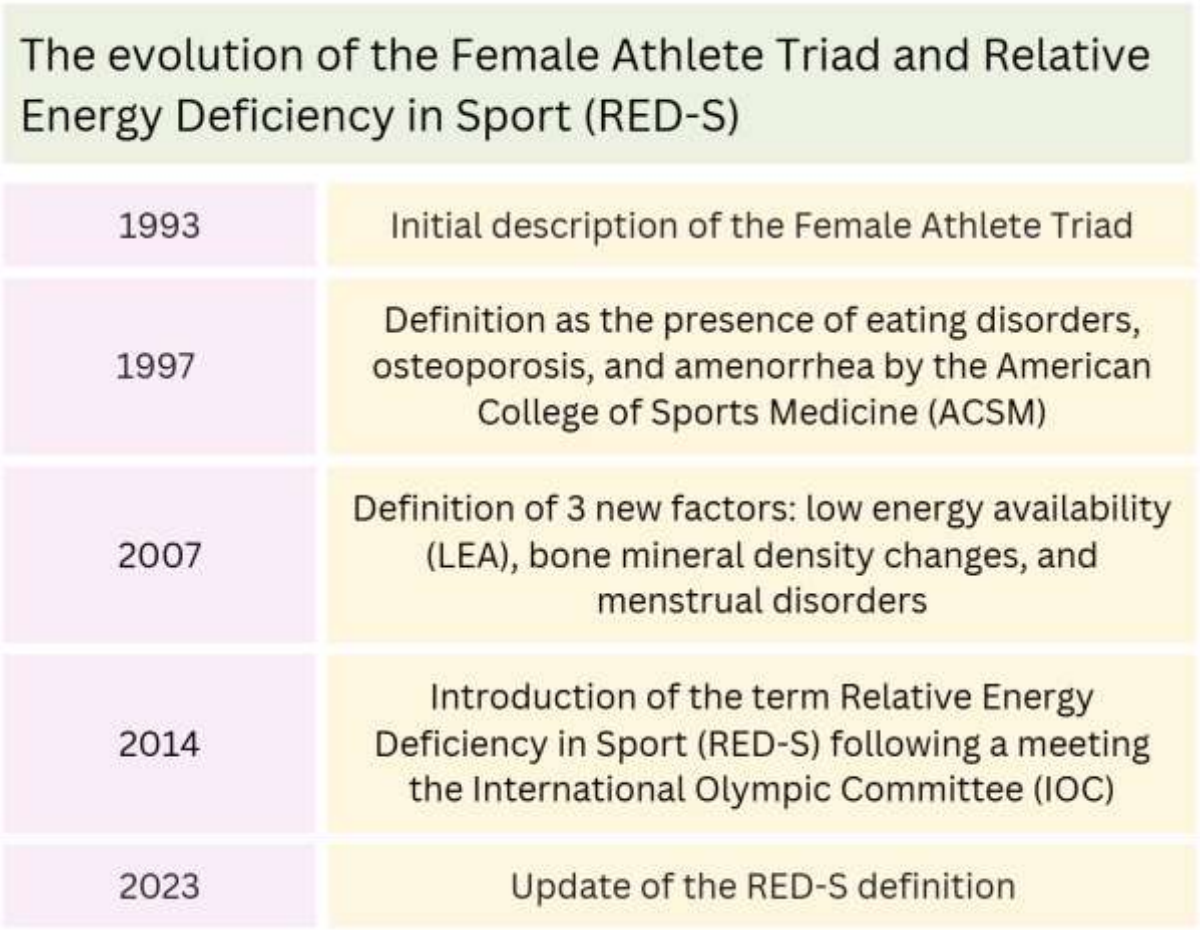

Figure 1. History of Female Athlete Triad and RED-S [9].

2. Pathophysiology of RED-S

The primary underlying factor of all symptoms and abnormalities described in the RED-S model is LEA, which, in both the short- and long-term, can lead to numerous maladaptive changes that negatively impact health, well-being, and athletic performance [10]. Energy availability (EA) is calculated by taking the difference between energy intake (EI) and exercise energy expenditure (EEE) divided by fat-free mass (FFM) [11]. The formula is shown in Figure 2. It includes total calories consumed per day and burned during exercises, as well as, body mass excluding fat [11]. LEA is defined as a daily EI of <30 kcal/kg FFM, while the optimal EA for weight maintenance and adequate physiological function in women is considered to be ≥45 kcal/kg FFM [12]. However, studies have shown that physiological disturbances in LEA are more influenced by reduced EI than by excessive EEE [13].

$$EA = \frac{EI\ [kcal] - EEE\ [kcal]}{FFM\ [kg]}$$

EA - Energy Availability
EI - Energy Intake
EEE - Exercise Energy Expenditure
FFM - Fat-Free Mass

Figure 2. Energy Availability Calculation Formula [11].

Another factor that contributes to the development of RED-S and accelerates this process, regardless of EI, is low-carbohydrate availability (LCA) [8]. Endurance exercise relies heavily on carbohydrates as a fuel source. Although it has been shown that consuming them before, during, and after exercise supports athletic performance, LCA is common, especially among female athletes [14]. Studies have shown that LCA has a harmful effect on iron levels, immune function, and bone health, and sometimes even in the absence of LEA [15, 16].

3. Epidemiology

The prevalence of LEA/RED-S varies widely, estimated at 23%-79.5% in female and 15%-70% in male athletes practicing various sports disciplines [8]. A meta-analysis by Gallant et al. reported the prevalence of LEA among 6118 athletes at 44.7%: 44.2% in females and 49.4% in males based on 46 studies, and found that 63.0% of 730 athletes were at risk of RED-S in 8 additional studies [17]. Individuals who participate in sports where a higher power-to-body-mass ratio benefits performance, such as track and field (athletics), cycling, gymnastics, combat sports (e.g., wrestling), rowing, triathlon, and synchronized swimming, are at increased risk of RED-S [18]. Among women in sports, LEA particularly affects gymnasts (44.8%), soccer players (33.3%) and ballet dancers (22%) [6]. Torres-McGehee et al. (121) conducted a study of female collegiate athletes and performing artists aged 19.8 ± 2.0 years. The participants included athletes from equestrian, ballet, soccer, beach volleyball, softball, and volleyball. Ninety-eight (81.0%) of them exhibited LEA, with the percentage among ballet dancers reaching 96.2%, while a risk of eating disorders (EDs) was identified in 92 (76.0%) [19]. In the study by Smith et al., among 19 cheerleaders aged 20.3 ± 1.2 years, 100% demonstrated LEA on training days. With respect to the Female Athlete Triad, 47.7% exhibited one component,

while 52.6% exhibited two components. Additionally, 52.6% were at risk of EDs, and the same percentage (52.6%) reported menstrual disturbances [20]. Para athletes may face a greater risk of LEA compared to able-bodied athletes, however its prevalence in this population has not yet been established [21].

4. Risk factors

Proper nutrition is essential for athletes to achieve good results. Therefore, increased training intensity requires an adequate supply of energy and macro- and micronutrients [22]. Inadequate EI, combined with a lack of knowledge about proper nutrition, can lead to nutritional deficiencies [23]. LEA is associated with insufficient intake of protein and carbohydrates, as well as vitamins, micro- and macronutrients such as vitamin D, calcium, magnesium, iron and zinc. The causes of LEA include both insufficient knowledge about nutrition and EDs, such as anorexia or bulimia [11]. Psychosocial factors that constitute a risk factor for RED-S include social media influence, dissatisfaction with body image, and social pressure, and in athletes, additionally, the desire to improve performance and pressure from the coaching environment [24]. ED associated with LEA can be both a risk factor and a consequence of RED-S [8].

5. Consequences of LEA

Short-term, LEA can have a positive effect on improving athletes' performance and coaches' satisfaction [25]. However, attention should be maintained, as in the long term it can expose the athlete to numerous health consequences. The identified adverse effects include impaired growth and development, as well as, function of reproductive, gastrointestinal, hematological, neurocognitive, cardiovascular systems, urinary incontinence, and impaired glucose and lipid metabolism. In addition to these, many adverse mental health effects of LEA and RED-S have been described: mood disturbances, decreased well-being, reduced sleep quality, exercise addiction, fear of injury, perfectionist tendencies such as striving for the “ideal” body shape, and even affective disorders and depression [8]. LEA causes a decrease in fat mass and BMI. It affects the reproductive system, and influences hormonal pathways. In LEA states, the levels of insulin, oxytocin, IGF-1 and anorexigenic leptin decrease in athletes of both sexes. Sex hormones - estradiol and progesterone in women and testosterone in men - also decrease. In women, the levels of adiponectin and anorexigenic ghrelin may increase [2]. The physiological consequences of LEA in men are low libido and reduced morning erections [26]. Female athletes experience menstrual disorders such as functional hypothalamic

amenorrhoea (FHA) [11]. In the study by De Souza et al., subtle menstrual abnormalities were reported in 50% of excercising women, while amenorrhea was observed in 33% [27]. The long-term consequences of LEA, in addition to endocrine and reproductive disturbances, may also include dyslipidemia, bradycardia, hypotension, low resting metabolic rate, injuries, hypoglycemia, and immunosuppression [12]. Shimizu et al. demonstrated that in female athletes, amenorrhea and low estrogen levels increase susceptibility to infections by impairing mucosal immune function [28].

RED-S also affects athletic outcomes. It decreases power and endurance performance, muscle strength, training response, motivation, and recovery [8]. In addition, it negatively affects athletes' performance by reducing coordination and concentration, impairing judgment, and causing irritability and depression [29]. LEA is regarded as a significant risk factor for injuries. Female athletes experiencing oligomenorrhea or functional hypothalamic amenorrhea (FHA) have been shown to sustain a higher proportion of severe musculoskeletal injuries, resulting in extended time lost from training and competition [12].

6. Diagnosis

A comprehensive clinical assessment, including a detailed medical history, as well as an evaluation of the athlete's dietary patterns, training volume, and psychological well-being, is essential for the diagnosis of RED-S [30]. Studies indicate that health and performance issues are often underrecognized, resulting in a lack of appropriate treatment for the disorder [31]. The International Olympic Committee developed the RED-S Clinical Assessment Tool-Version 2 (IOC REDs CAT2), replacing the original IOC REDs Clinical Assessment Tool (CAT) published in 2015. The IOC REDs CAT2 stratifies athletes' severity and risk into 4 categories: green, yellow, orange and red, ranging from very low to extreme risk, with corresponding clinical criteria and management recommendations. Green includes none to very low risk and requires no treatment. Yellow and orange involve mild and moderate to high risk, respectively, and require treatment, monitoring, and possible modification of training or competition. Red represents very high to extreme risk, necessitating immediate clinical intervention with possible hospitalisation and frequent monitoring, significant training adjustments, and in severe cases, removal from all training and competition [8]. In the study by Peklaj et al., which included 150 athletes (77 women and 73 men) and applied the RED-S CAT tool, 29% were classified in the green group, 64% in the yellow group, and 7% met the criteria for the red group [31]. Another tool for identifying an increased risk of LEA based on symptom history is the Low Energy

Availability in Females Questionnaire (LEAF-Q). The questionnaire is brief and easy to administer, enabling the early detection and the implementation of intervention [32]. It includes questions regarding injuries and the functioning of the gastrointestinal and reproductive systems [33]. In a study by Melin et al. involving 84 female athletes aged 18-39, the questionnaire demonstrated a sensitivity of 78% and a specificity of 90% [32]. Kroshus et al. conducted a study involving 285 athletic trainers. Among them, 281 (98.61%) had heard of the Female Athlete Triad, while only 94 (32.98%) had heard of RED-S. Awareness of these disorders helps identify the problem among athletes and provide appropriate care [34].

7. Treatment of RED-S

Treatment of the RED-S syndrome should be based on reversing the problematic LEA by restoring adequate EA by raising EI and reducing EEE, taking into account its possible causes, and on preventing long-term health consequences [6, 35, 36]. It is important to pay attention to the assessment of specific body systems and to screen for complications such as psychological disorders, low BMD, menstrual dysfunction, cardiovascular impairment or gastrointestinal disorders [29]. A promising treatment for BMD, improving bone parameters in female endurance athletes with oligo-/amenorrhea, is a transdermal patch containing 17β-estradiol in combination with cyclic oral administration of micronized progesterone [37]. Appropriate dietary changes are essential for restoring optimal EA and adequate levels of macro- and micronutrients [22]. However, this is not an intervention that is easy for patients to accept. In a study by De Souza et al., which involved physically active women with oligomenorrhea and amenorrhea, the goal was menstrual recovery through increased daily EI (330 ± 65 kcal/day; 18 ± 4%). The percentage of participants who dropped out of the study in the increased calorie group was 57% [38]. Given the complexity of the problem and the variety of possible complications, treatment should be multidisciplinary, including dietary, medical, and psychological support from specialists such as dietitians, doctors, and psychologists, as well as support from families, the sports community, and coaches [6, 8]. Ensuring sufficient EI and carbohydrate availability allows elite athletes to meet physiological demands while lowering the risk of adverse effects on health and performance [14].

8. Conclusions

Although driven by ambitious goals, the pursuit of perfection, including striving for an "ideal" body composition or peak performance, can adversely impact health, leading to RED-S, which has wide-ranging consequences on multiple physiological systems, mental health, and athletic performance, particularly in athletes participating in aesthetic, endurance, or weight-class sports. Addressing RED-S requires a multidisciplinary approach that combines nutritional education, medical monitoring, psychological support, and the promotion of a sporting culture that prioritizes health alongside performance. Raising awareness among athletes, their families, and coaches about the possibility and severity of the disorder allows for the development and implementation of strategies that support both the mental and physical health of athletes.

Disclosure Section

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