

REVIEW ARTICLE

A Narrative Review of Low Energy Availability

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ABSTRACT

Low energy availability (LEA) occurs due to insufficient calorie consumption to promote exercise energy expenditure, compromising normal physiological functions in both genders, thus, results in relative energy deficiency in sport (RED-S). This review on LEA is conducted to explore the origin of this concept, its correlation to the Female Athlete Triad and RED-S, as well as the risks and effects. This narrative review is written on several English-based research articles dated from 2000 to 2020 in PubMed, Google Scholar, and the Web of Science databases related to LEA. Disordered eating and exercise addiction are found to be the risk factors for LEA. LEA negatively affects neuromuscular function, recovery, and raises the chance of injuries and illness, all of which can have a negative impact on performance. The severity of this condition may influence the decisions about the level of care and return to play or exercise, requiring a multidisciplinary approach.

Keywords: Low energy availability, Exercise energy expenditure, Relative energy deficiency in sports, Female athlete triad, Physiological disturbances

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INTRODUCTION

According to most prevalence studies, up to 50% of sportswomen over the world experience modest menstruation irregularities, and 33% of women have amenorrhea (1). Functional Hypothalamic Amenorrhea (FHA) is a menstrual dysfunction that is highly related to REDS, that develops when the hypothalamic-pituitary-gonadotropin axis alters owing to a low energy availability (LEA). FHA has long-term health implications such as osteopenia/osteoporosis and infertility (2). Poor bone health can also be caused by LEA, which is mediated by hormone imbalances and/or nutritional deficiencies (3,4). The incidence of osteopenia among sportsmen is estimated to be 2250%, while the prevalence of osteoporosis is 13% (5).

A local study by Quah et al. (6) found that the frequency of the female athlete triad was low (1.9%), but a high incidence of individual triad components in the lean group among Malaysian elite female athletes. From the mentioned study, in the lean group, 47.6%, 13.3%, and 89.2% of women were at risk of menstrual irregularity, poor bone quality and eating disorders, respectively; as opposed to 14.3%, 8.3%, and 89.2% in the non-lean group (6). A commentary by Burke et al. (7) on selected

male athlete groups; rowers, jockeys, combat sports and distance runners (specifically from East Africa), revealed a startling high prevalence of LEA due to weight-making practices and nature of the sports events that resulted in excessive energy expenditure and disordered eating among the athletes.

Energy Availability (EA) can be defined as the dietary energy that can be used to maintain physiological functions after subtracting the energy cost of exercise (8). It shows the difference in energy intake (EI) and exercise energy expenditure (EEE) divided by fat-free mass (FFM), using the following formula; $EA = (EI - EEE) / FFM$. The threshold for optimal EA for physiological processes is 45 kcal/kg FFM/day for inactive eumenorrheic normal weight women and 40 kcal/kg FFM/day for exercising males (9,10). Any physically-active person should aim for energy availability of 30 and 45 kcal/kg FFM/day (125-188 kJ/kg FFM/day) for weight loss, around 45 kcal/kg FFM/day for weight maintenance, and more than 45 kcal/kg FFM/day for growth and carbohydrate loading as tabulated in Table I (11).

The body decreases reproductive activity and bone formation when EA is decreased to 30 kcal/kg FFM/day, a condition known as the Low EA (LEA); the body suppresses reproductive function and bone formation (12,13). This physiological response occurred to restore energy balance and extend survival but at the expense of impairing reproductive and skeletal health (14). LEA arises when an athlete's calorie intake is insufficient to

Table 1: Example of Energy Availability (EA) calculation

Example	Body weight (kg)	Body fat (%)	FFM (kg)	EI (kcal * day ⁻¹)	EEE (kcal * day ⁻¹)	EA = (EI-EEE)/ FFM (kcal*kg / FFM*day)
Low energy availability	61.5	13.5	53.2	1422	520	17
Weight loss	61.5	13.5	53.2	2382	520	35
Weight maintenance	61.5	13.5	53.2	2914	520	45
Carbo-hydrate loading	61.5	13.5	53.2	3192	0	60

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

meet the energy requirements of daily life as well as training needs. Deficient of EA caused by increased of exercise intensity/frequency, decreased energy intake, or both can disturb the endocrine milieu (9).

As a result, the Female Athlete Triad, its male counterpart, and the Relative Energy Deficiency in Sport (RED-S) models all consider LEA to be a crucial etiological factor behind a slew of physiological dysregulations (1,15). This notion, which was originally based on female-specific physiological responses, has lately been extended to males, where experimental proof is still scarce (8). Unbeknownst to many, a seemingly healthy and fit person may have underlying etiologies for the aforementioned nutritionally deficient conditions in the first place, manifested as trivial symptoms (i.e., excessive lethargy following intense physical training regime) and frequently dismissed by many doctors as mere fatigue or body ache following a heavy workout, without further evaluation. This review aims to explore the origin of the LEA concept, its correlation to the Female Athlete Triad and RED-S, as well as the risks and effects.

METHODS

This narrative review is written on several research papers and journals published regarding LEA and RED-S. PubMed, Google Scholar, and Web of Science databases are used to extract the related papers and journals. Combinations of the following key search terms were included: EA, low EA, LEA risk, awareness of LEA, Female Athlete Triad, eating disorders, nutrition education/diet intervention, and RED-S. The selection criteria for the source materials of this review are research publications between 2000 to 2020, English-based literature and deemed relevant as well as appropriate in accordance to the narrative reviews main topic and purpose concerning clinical exercise science. The IOC Consensus Statement, both in 2014 and 2018, served as the main focal point of reference for definition and elaboration of Female Athlete Triad based on clinical diagnosis and treatment plan from the RED-S CAT. Several other articles and lecture series related to nutrition and sports medicine

fields of practice are used to further expand the scope of this narrative review. A total of 37 research articles and position stand / consensus relating to LEA and female athlete triad are reviewed and summarized to depict the depth of the topic of discussion. Two other sources of reference from the American Psychiatric Association (APA), are included here to explain the diagnosis of eating disorder as risk factor for LEA. The illustration of the physiological disturbances caused by LEA is derived from Encyclopedia of Endocrine Diseases (2nd edition) to give a clearer and bigger picture of what's happening inside of a person with LEA. All the information gathered are later rearrange for a smooth narration in order to explain the relationship of LEA in female athlete triad, its connection to RED-S, the risk factors contributing to LEA and the health sequelae caused.

RESULTS

History and origin of the concept

Female Athlete Triad

In 1986, the Female Athlete Triad concept was introduced to describe the interrelated problems of eating disorders, unhealthy bone, and menstrual dysfunction seen in female athletes (16). This concept was first discovered and coined by the late Dr. Barbara Drinkwater, FACSM; the first female president of the American College of Sports Medicine (ACSM). Eating disorders are divided into Anorexia Nervosa (lack of appetite with an obsession to lose weight) and Bulimia Nervosa (excessive purging following bouts of binge-eating with an obsession for weight loss). Unhealthy bone status is determined by Bone Mineral Density (BMD) through DEXA Bone scan either osteopenia (reduced bone mineral) or osteoporosis (brittle bone). Menstrual dysfunction focuses on amenorrhea (absence of periods) be it primary (failure of menses to occur by the age of 13) or secondary (cessation of menses after attaining menarche) (16).

Women participating in competitive sports (involving weight categories and aesthetic attributes) are at higher risk of developing Female Athlete Triad; a term which was first coined during a panel convention by the American College of Sports Medicine (ACSM) in 1992. A new definition of the Triad was then introduced in 2007 by the ACSM which incorporated an inter-related syndrome of low energy availability (LEA) with or without disordered eating, functional hypothalamic amenorrhea, and altered bone mineral density (17).

The Female Athlete Triad is a phenomenon that affects physically active girls and women which may lead to Relative Energy Deficiency in Sports (RED-S), which can have a major impact on their peak performance and as a result, their post-athletic careers. The Female Athlete Triad spectrum is depicted in Figure 1 (18). Because the triad's components are interconnected, identifying athletes who are at risk of developing any of the triad's

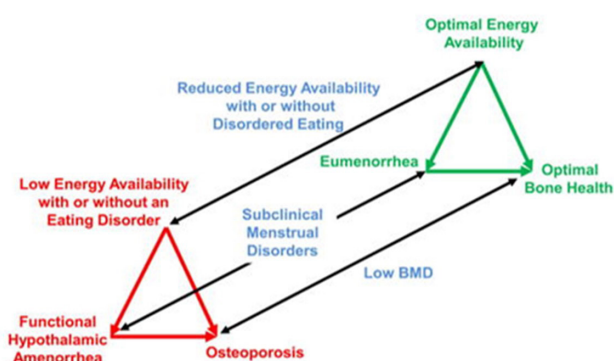


Figure 1: Female Athlete Triad spectrum [source: (1)]

components, particularly those who participate in sports that promote a lean physique, is critical for further diagnosis (6).

Weight has a big impact on an athlete's performance, whether it's to get into a better weight category or to change specific sports techniques and maneuvers, with the ultimate goal of winning the game. Participants in aesthetic and weight-dependent sports were found to be at risk of the Triad in previous investigations (19,20). The formation of the Triad is fuelled by the pressure put on young women to acquire or maintain an abnormally low body weight. Adolescents and women who participate in sports in where low body weight is prioritised for athletic performance or aesthetics are more at risk. Girls and women who have one of the Triad's components should be tested for the others. Female Athlete Triad diseases can reduce physical performance and cause morbidity and mortality when they occur alone or in combination (19). In short, the significant incidence of LEA experienced in the female athletic population explains the Female Athlete Triad manifestation among active ladies (37).

Relative Energy Deficiency in Sports (RED-S)

Beyond the Female Athlete Triad: Relative Energy Deficiency in Sport (RED-S) was a consensus statement made by the International Olympic Committee (IOC) in 2014. The RED-S syndrome refers to the "impaired physiological function including, but not limited to, metabolic rate, menstrual function, bone health, immunity, protein synthesis, cardiovascular health caused by relative energy deficiency" (21 p491). This syndrome includes male athletes / exercising men as having LEA too, albeit with somewhat lesser health effects. LEA is defined as a discrepancy between an athletes energy intake (diet) and the energy burned during exercise, resulting in insufficient energy to support the normal physiological activities that are necessary for optimal health and performance (15). Various studies show that LEA causes body-wide effects for both genders, recognizing RED-S as a multifactorial debilitating condition among athletes (39). The Female Athlete Triad is screened out among ladies active in high-performance sports and regular physical activity

previously using LEAF-Q (Low Energy Availability in Females Questionnaire) until 2013, and RED-S CAT (Relative Energy Deficiency in Sports Clinical Assessment Tool) since 2014 as proposed, developed and championed by the IOC Medical Commission Group with the inclusion of male athletes, specific treatment as well as Return To Play (RTP) guidelines for multidisciplinary healthcare approach, in particular among sports doctors and nutritionists (22).

Risk factors of LEA

Eating Disorders

Eating disorders are illnesses where people's eating habits are severely disturbed. People with eating disorders are usually pre-occupied with food and their body weight (23). Several million active women are affected by eating problems, which cause them to consume less calories on a regular basis. There are two main types of eating disorders that worried most healthcare practitioners as well as nutritionists and dietitians to LEA and RED-S, based on the Diagnostic and Statistical Manual of Mental Disorders, 5th edition by the American Psychiatric Association (APA), which are the Anorexia Nervosa and Bulimia Nervosa (24). Anorexia Nervosa is described as the inability to maintain a minimally normal weight ($BMI < 17 \text{ kg/m}^2$) accompanied by a dreadful fear of weight gain as indicated by obsessive weight-loss behaviours, and a disruption in the way body weight and form are viewed (24). It is divided into restricting (severe limitation of food intake) and binge-eating / purging types. On the other hand, Bulimia Nervosa is characterised by recurrent binge eating followed by recurrent inappropriate compensatory mechanisms such as self-induced vomiting, abuse of laxatives, diuretics or other medications, and prolonged fasting practice to prevent weight gain (24).

Exercise Addiction

Disordered eating (DE) or eating disorder (ED) is linked to perfectionism and obsessive exercise, as well as an unwillingness to reduce the training load, resulting in negative effects such as injury and emotional anguish (25). Current research reveals that compulsive exercise behaviour is linked to perfectionism, disordered eating symptoms and obsessive-compulsive traits in both male and female long-distance runners (25).

Male endurance athletes are tested using the Eating Disorder Examination Questionnaire (EDE-Q) and found that disordered eating symptoms were linked to higher total exercise dependence ratings. Those with higher exercise dependence scores trained more frequently (around 11 hours/week) than those with lower scores (around 8 hours/week). Furthermore, they also did not adjust their energy intake to meet increased energy needs, resulting in more pronounced LEA (26). Higher subscale exercise dependence scores are likewise linked to lower blood glucose, testosterone, and cortisol ratios, as well as a higher cortisol and insulin ratio,

implying a link between biomarkers of RED-S and compulsive exercise behaviour. Further exploration on the relationship between disordered eating behaviour, compulsive exercise and RED-S in various sports and groups of athletes (e.g.: gender, performance level and age) is needed, as athlete with compulsive exercise are more likely to have underlying disordered eating behaviour, thus, at greater risk of health consequences due to LEA (27).

Health Consequences of LEA

With LEA predisposing to Female Athlete Triad and a higher RED-S, negative health outcomes will be felt throughout the body. Menstrual dysfunction as the major component of the Female Athlete Triad is linked to a female-specific complications such as long-term fertility issues and functional hypothalamic amenorrhea, causing in emotional and psychological consequences later on (12,28). Another component of the Female Athlete Triad is the unhealthy bone composition (Osteopenia or Osteoporosis), as a result of hypo-estrogenemia. This condition will inadvertently put female athletes at risk of stress fracture (29-31). Figure 2 illustrated the summary of pathophysiology influenced by LEA resulting in a myriad of female related symptoms (32).

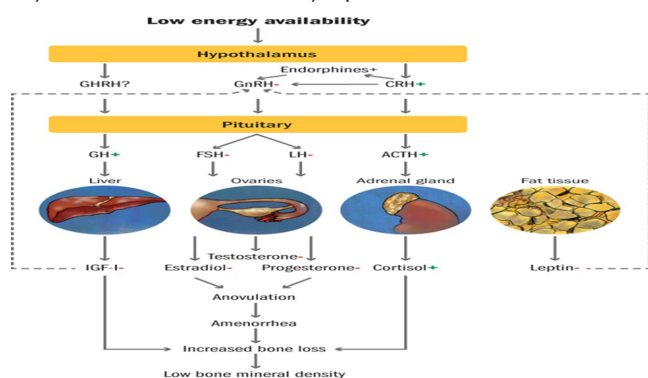


Figure 2: Summary of physiological disturbances in LEA [source: (32)]

Further investigation into the physiological impacts reveals that LEA causes endothelial dysfunction and aberrant lipid metabolism, leading to the completion of Virchow's triad (the other being blood flow stasis), predisposing for chronic heart issues in the long run. Reduction in the glucose utilization and mobilization of fat stores due to slowing of metabolic rates (low basal metabolic rate (BMR)) results in decreased production of growth hormone (12,33). Further to it, the resulting effects of stunted growth and poor muscle strengthening affect the psychosocial development of athletes, rendering them into unnecessary stress and depression episodes. Finally, nutritional deficiency can occur due to eating disorders, that can cause anaemia and chronic fatigue which increase the likelihood of a repetitive history of infections (17).

The RED-S effect is later revised by a myriad of negative

health outcomes, adapted from the IOC consensus statement with the integration of Exercise-Hypogonadal Male Condition (EHMC) via the inclusion of Male and Female Athlete Triad (15,21). The exact physiological mechanism of EHMC which caused the testosterone reduction in men is still unknown, however, it is thought to be malfunction of the hypothalamic-pituitary-testicular (HPT) regulating axis (34). Henceforth, the EHMC causing an imbalance of the hormonal system, particularly testosterone reduction, exposed the active exercising males and endurance athletes to unhealthy bone conditions such as osteopenia or osteoporosis, which eventually lead to the stress fracture. Lastly, suppressed testosterone results in diminished sexual libido (34).

CONCLUSION

Low energy availability (LEA) is not a single entity resulting in excessive fatigue during exercise or sports. It is a part of the Female Athlete Triad, interrelating with other components namely menstrual disturbance and low bone mass density. LEA resulting in impaired Functional Hypothalamic Amenorrhea (FHA) along with its counterparts in Female Athlete Triad form the foundation of the bigger Relative Energy Deficiency in Sports (RED-S) concept; which incorporated the male pathophysiological pathway of Exercise-Hypogonadal Male Condition (EHMC) together as part of the inclusive diagnosis, as proposed by the IOC Medical Commission Group. Diagnosis and care of this disease involving both genders engaging in intense physical activity regime and high-performance sports is a multidisciplinary approach, hence warrant the cooperation between sports physician, sports nutritionist, and clinical exercise physiologist within the medical fraternity. Various studies of LEA provide data on its prevalence, RED-S symptoms involvement, local female elite athletes, and selected male athlete groups separately. Risk factors such as eating disorders and exercise addiction are found to be correlated between one another and heavily influenced LEA based on the psychological effect studies conducted with the addition of proper diagnosis based on DSM-5 by APA. The health sequelae of LEA are detailed out based on its effect on the physiological process and found to be significantly influencing the reproductive system for both genders (EHMC for men and FHA for ladies). In conclusion, this review supports the theory that LEA is a potential threat for anyone engaging in exercise regimes or high-performance sports that later became the focal point in the pathophysiology of numerous health consequences.

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