The effect of relative energy deficiency syndrome in female athletes

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ABSTRACT

Relative Energy Deficiency in Sport (REDs) is a multisystem condition caused by prolonged low energy availability, in which dietary energy intake is insufficient to support both exercise demands and essential physiological functions. In female athletes, REDs represents a significant health and performance concern, affecting endocrine, skeletal, metabolic, immune, cardiovascular, and psychological systems. Chronic low energy availability leads to adaptive suppression of physiological processes, particularly reproductive function, resulting in menstrual disturbances, hypoestrogenism, and impaired bone health. These changes increase the risk of stress fractures, recurrent injuries, delayed recovery, and long-term health consequences. REDs may develop even in athletes with stable body mass and body fat within normal ranges, complicating early detection. Psychological stress, sport-specific pressures, disordered eating behaviors, and inadequate nutritional strategies further contribute to its development. Endurance, aesthetic, and weight-category sports present the highest risk. This narrative review summarizes current evidence on the pathophysiology, risk factors, clinical presentation, and management of REDs in female athletes. Management focuses on restoring adequate energy availability through nutritional rehabilitation, training modification, and psychological support within a multidisciplinary framework. Physiotherapists play a key role in early recognition, monitoring recovery, and facilitating a safe return to sport. **Keywords:** Relative Energy Deficiency in Sport, low energy availability, female athletes, physiotherapy, sports nutrition

Vpliv sindroma relativnega energijskega primanjkljaja na zdravje športnic

POVZETEK

Sindrom relativnega energijskega primanjkljaja v športu (SREP) je kompleksno, večsistemsko stanje, ki nastane zaradi dolgotrajne nizke energijske razpoložljivosti, pri kateri energijski vnos ne zadostuje za pokrivanje zahtev telesne vadbe in osnovnih fizioloških funkcij. Pri športnicah SREP predstavlja pomemben zdravstveni in funkcionalni problem, saj prizadene endokrini, kostni, presnovni, imunski, srčno-žilni in psihološki sistem. Kronični energijski primanjkljaj vodi v prilagoditveno zaviranje fizioloških procesov, zlasti reproduktivne osi, kar se kaže v menstrualnih motnjah, hipoestrogenizmu in zmanjšani kostni mineralni gostoti ter povečanem tveganju za stresne zlome in ponavljajoče se poškodbe. SREP se lahko razvije tudi pri športnicah z navidezno stabilno telesno maso in normalnim deležem telesne maščobe, kar otežuje zgodnje prepoznavanje in pogosto vodi v pozno diagnozo. Pomembno vlogo pri razvoju sindroma imajo tudi psihološki stres, kulturni pritiski v športu, motnje hranjenja ter neustrezno prilagojene prehranske strategije. Največje tveganje je prisotno v vzdržljivostnih, estetskih in težnostnih športih. Pregledni članek povzema sodobna spoznanja o patofiziologiji, dejavnikih tveganja, kliničnih znakih in stopnjah SREP pri športnicah, pri čemer je nizka energijska razpoložljivost opredeljena kot osrednji etiološki mehanizem. Obravnavani so tudi pomen makrohranil, specifične energijske zahteve ter vloga kliničnega orodja IOC REDs CAT2. Celostna obravnava temelji na multidisciplinarnem pristopu, pri katerem ima fizioterapevt ključno vlogo pri zgodnjem prepoznavanju, spremljanju okrevanja in varnem vračanju v šport. **Ključne besede:** sindrom relativnega energijskega primanjkljaja, nizka energijska razpoložljivost, športnice, fizioterapija, športna prehrana

INTRODUCTION

Relative Energy Deficiency in Sport (REDs) results from insufficient energy availability to support essential physiological functions (1). Energy availability refers to the energy remaining after exercise for basic processes such as cellular function, thermoregulation, growth, reproduction, immune function, and movement (2). While short-term low energy availability (LEA) may lead to loss of fat and lean mass, chronic LEA is more concerning, as it triggers adaptive suppression of physiological systems, disrupts hormonal balance, impairs bone health, and increases injury risk (3).

Risk factors for REDs include disordered eating behaviors, restrictive dietary patterns, eating disorders, life transitions (e.g., relocation or changes in coaching), and environmental stressors, all of which may negatively affect mental health (1). Although REDs can occur in all sports, it is most prevalent in endurance disciplines, where low body mass is often perceived as beneficial (4). In women, chronic LEA reduces estrogen levels, leading to menstrual dysfunction, decreased bone mineral density, and increased risk of stress fractures, making female athletes particularly vulnerable (3).

Diagnosis is based on LEA accompanied by at least one clinical sign, such as menstrual disturbances, infertility, altered reproductive hormone levels, elevated cortisol or ghrelin, reduced bone mineral density, decreased resting metabolic rate, disordered eating, or low ferritin levels. Importantly, REDs may occur even in athletes with stable body mass and body fat above 21%, as the body preserves adipose tissue to protect vital organs (5). Psychological stress further increases risk, making blood biomarkers essential for early detection in this frequently underdiagnosed group (3).

Management requires a multidisciplinary approach, involving medical professionals, a sports dietitian, and coaching staff, with psychological support when eating disorders are present (6). Treatment focuses on restoring adequate energy availability through increased intake and/or reduced training load, with individualized adjustments based on REDs severity. In severe cases, training cessation or hospitalization may be necessary, and ongoing monitoring of body composition, hormonal status, and menstrual function is essential during recovery (7).

Despite growing awareness and available guidelines (1), implementation in daily sports practice remains limited. Many coaches lack training in REDs recognition and management. Physiotherapists play a key role in early detection through monitoring performance, recovery, and injury patterns. In sports where low body weight is culturally reinforced—such as cycling, ski jumping, and rhythmic gymnastics—unhealthy practices persist, disproportionately affecting female athletes (8). Therefore, early identification, effective treatment, and prevention of REDs remain critical challenges for sports and healthcare professionals.

THE ROLE OF MACRONUTRIENTS IN SPORTS NUTRITION

Carbohydrates

Carbohydrates (CHO) are stored in the body primarily in the form of glycogen and, to a lesser extent, as free glucose in the bloodstream. The largest glycogen stores are located in skeletal muscle, where muscle glycogen serves as a direct energy source for muscular work during physical activity. A substantial portion of glycogen is also stored in the liver, where it plays a crucial role in maintaining stable blood glucose levels, particularly during fasting or prolonged exercise.

A small amount of free carbohydrates is continuously present in the blood as glucose, which is essential for the function of the brain, nervous system, and red blood cells. When glycogen stores are fully replenished and energy intake exceeds the body's requirements, excess glucose can be converted into fat and stored in adipose tissue.

Adequate carbohydrate intake is a key determinant of exercise performance, especially before, during, and after intense training sessions and competitions. Sufficient carbohydrate availability is particularly important for endurance athletes, as inadequate carbohydrate intake may reduce endurance capacity and impair training adaptations (9).

Thomas et al. provide systematic recommendations for carbohydrate intake based on exercise intensity and duration (10). For light exercise lasting less than one hour, a daily intake of 3–5 g CHO/kg body mass is sufficient. Athletes performing moderate exercise for approximately one hour require 5–

7 g/kg/day, whereas those engaging in high-intensity exercise lasting one to three hours require 6–10 g/kg/day. In extreme cases, such as athletes training four to five hours per day at high intensity, carbohydrate requirements may reach 8–12 g/kg body mass per day.

Among endurance athletes, carbohydrate requirements vary according to training volume. Elite endurance athletes may accumulate weekly training loads ranging from 10–12 hours in middle-distance runners to 25–30 hours in triathletes and cyclists. Burke et al. emphasize that for this population, carbohydrate availability at critical training and competition moments is more important than absolute daily intake alone (11).

Aragon et al. confirm that low glycogen stores impair performance during high-intensity exercise (11), while Burke et al. demonstrate that fully replenished glycogen stores enhance performance capacity during such activities (11). Currell et al. further highlight that carbohydrate intake during exercise not only provides substrate for energy production but also supports neuromuscular metabolic processes and helps prevent cognitive fatigue (13).

Proteins

Unlike carbohydrates and fats, proteins do not have a dedicated storage depot in the body. Instead, they are integral components of all tissues and structures, including skeletal muscle, organs, enzymes, hormones, immunoglobulins, and numerous other protein molecules. The International Olympic Committee (14) recommends a protein intake of 1.6–1.7 g/kg body mass for athletes. These values exceed recommendations for the general population and reflect the increased protein requirements associated with training-induced recovery and adaptation.

Importantly, protein intake is not determined solely by total daily quantity but also by timing and distribution throughout the day. Kerksick et al. emphasize that the timing of protein ingestion relative to training and the type of protein consumed may be more influential than absolute protein intake alone (15). Athletes are therefore advised to consume multiple protein-containing meals throughout the day, typically providing approximately 20 g of protein per serving, particularly in close temporal proximity to training sessions.

Protein requirements vary according to the athlete’s specific goals. For maintenance of muscle mass, intakes of 1.4–2.0 g/kg body mass are generally sufficient. During periods of body mass reduction, however, protein requirements increase substantially. Jäger et al. report that intakes of 2.3–3.1 g/kg body mass may be necessary to preserve lean mass under hypocaloric conditions (16). In certain individuals, very high protein intakes exceeding 3 g/kg body mass have been associated with reductions in fat mass while maintaining muscle mass in trained athletes.

Interestingly, Hartman et al. observed that well-trained athletes may exhibit lower relative protein requirements compared with untrained individuals, likely due to long-term training adaptations (17). Phillips et al. caution that inadequate protein intake leads to a negative nitrogen balance, characterized by increased protein catabolism and impaired recovery (18). When negative nitrogen balance persists, it may result in muscle loss, increased injury risk, illness, and reduced tolerance to training.

Fats

Fats are stored in the body primarily as triglycerides in adipose tissue, which represents the largest energy reserve. In addition, fats are stored as intramuscular triglycerides, where they are available as an energy source during prolonged exercise of moderate intensity. Fat storage occurs when energy intake exceeds energy expenditure over an extended period, with excess dietary energy converted into triglycerides and deposited in adipose cells.

Fats are utilized as a primary energy source during prolonged, moderate-intensity physical activities such as running or cycling. The body also increases reliance on fat oxidation during periods of fasting or sleep, when glucose availability is reduced. Similarly, low-carbohydrate diets promote greater utilization of fat as an energy substrate. Consequently, fats represent an essential energy source for long-duration exercise and for maintaining survival during periods of limited food availability.

Adequate fat intake is required throughout all phases of training, as fats facilitate the absorption of fat-soluble vitamins, contribute to hormone synthesis, and maintain the structural integrity of cell membranes and the myelin sheaths of nerve fibers. Intramuscular triglycerides provide an important energy source during prolonged moderate-intensity exercise, up to approximately 85% of VO_2max. In sports where speed is a key performance factor, this type of training is particularly important during the general preparatory phase, during which endogenous fat stores represent a significant fuel source. For endurance training sessions lasting longer than two hours, fat intake should support the replenishment of intramuscular triglyceride stores, corresponding to approximately 2 g of fat per kilogram of body mass per day (19). Accordingly, endurance athletes are generally advised to consume 1.5–2.0 g of fat per kilogram of body mass per day during such training phases (20). Excessive fat intake, however, may negatively affect muscle glycogen resynthesis and tissue recovery by displacing carbohydrate or protein intake (21).

ENERGY REQUIREMENTS AND NUTRITIONAL RECOMMENDATIONS

Adequate energy availability represents the foundation of every athlete's nutrition, as it enables optimal physiological function and supports healthy body composition. As emphasized by Thomas et al., athletes must carefully align energy intake with the demands of a periodized training process, as energy requirements continuously fluctuate depending on training intensity and volume throughout different phases of training (10). Proper sports nutrition is therefore a continuous process that must be addressed before, during, and after training.

Nutrition Before Training

One of the primary causes of fatigue during endurance exercise is the depletion of muscle and liver glycogen stores. As little as one rest day combined with sufficient carbohydrate intake (approximately 10 g/kg body mass per day or more) is generally sufficient to restore glycogen reserves. To optimize glycogen storage, various carbohydrate-loading strategies have been developed. For prolonged activities lasting more than 90 minutes, athletes are advised to consume 10–12 g of carbohydrates per kilogram of body mass during the 36–48 hours preceding competition (11).

Pre-exercise meals should ideally be consumed three to four hours before activity and accompanied by adequate hydration. Meals should be low in fat and fiber to minimize gastrointestinal discomfort and facilitate gastric emptying. Especially before important competitions, athletes are advised to consume familiar foods (22). Depending on individual needs, 1–4 g of carbohydrates per kilogram of body mass may be consumed 1–4 hours before exercise. A meal consumed three to four hours prior to activity may also include 1–2 g of carbohydrates and 0.15–0.25 g of protein per kilogram of body mass.

Nutrition During Training

During endurance exercise, adequate intake of carbohydrates, fluids, and sodium is essential. Intake requirements depend on exercise duration, intensity, and environmental conditions. For exercise lasting 30–75 minutes, small amounts of water or a limited intake of a sports drink are generally sufficient, with a recommended carbohydrate concentration of 5–10%.

For exercise lasting 1–2 hours, an intake of approximately 30 g of carbohydrates per hour is recommended. During longer sessions lasting 2–3 hours, carbohydrate intake should increase to 60 g per hour, while activities exceeding 2.5 hours may require up to 90 g of carbohydrates per hour (10).

Nutrition After Training

Post-exercise nutrition plays a crucial role in effective recovery. Research consistently shows that carbohydrates and proteins should be consumed as soon as possible after exercise to accelerate glycogen resynthesis and enhance the anabolic response (15).

Following prolonged endurance exercise lasting more than one hour, priority should be given to replenishing glycogen stores through carbohydrate intake of 1.2–1.5 g/kg body mass, followed by protein intake of approximately 0.3 g/kg body mass to stimulate muscle repair. Fat intake should remain moderate (0.2–0.3 g/kg body mass). After short-duration, high-intensity, or resistance-based training sessions lasting 20–40 minutes, recovery meals should follow a similar structure but contain minimal fat. For shorter, technically oriented training sessions with relatively low energy expenditure, a recovery meal consisting of 0.5–1.0 g of carbohydrates and 0.3 g of protein per kilogram of body mass is sufficient (23).

When less than four hours are available between training sessions, rapid glycogen restoration becomes critical. In such cases, meals should provide 1.2–1.5 g of carbohydrates per kilogram of body mass, with minimal fat and protein content. Easily digestible foods and sodium-containing beverages are recommended to promote fluid retention. During the first 2–4 hours post-exercise, frequent intake of small meals or liquids every 15–20 minutes is advised. If adequate carbohydrate intake cannot be achieved, supplementation with approximately 0.4 g of protein per hour may support glycogen restoration (10).

LOW ENERGY AVAILABILITY

LEA represents the central concept underlying REDs. LEA is defined as a state in which, after accounting for the energy cost of exercise, an insufficient amount of energy remains available to support the basic physiological functions required to maintain health, normal bodily systems, and optimal athletic performance (8). Energy availability (EA) is mathematically expressed as the difference between daily energy intake and exercise energy expenditure, divided by kilograms of fat-free mass (FFM), and is reported as kcal/kg FFM/day (24).

Energy expenditure during physical activity can vary substantially depending on the individual's activity level. In the general population, exercise energy expenditure typically accounts for approximately 20–30% of total daily energy expenditure. Endurance exercise includes a variety of rhythmic activities such as walking, running, cycling, swimming, triathlon, skiing, and related disciplines. During prolonged rhythmic exercise, such as cycling or running, muscle contractions are brief, blood flow to active muscles is only minimally restricted, and changes in blood pressure are negligible (24).

Sports in which success depends on the generation of high force over short time periods are classified as strength- and power-based sports. Typical speed and power disciplines include middle-distance running, track cycling, rowing, kayaking, canoeing, and swimming (25). Isometric or static contractions involving high force over short durations can compress intramuscular blood vessels, thereby restricting blood flow and oxygen delivery while simultaneously increasing blood pressure (24).

Recent epidemiological data indicate that REDs affects approximately 15–80% of elite athletes, with prevalence strongly dependent on sport discipline. LEA may develop intentionally through conscious reduction of energy intake aimed at lowering body mass or improving body composition. It may also occur unintentionally when athletes increase training load and energy intake but fail to meet the energetic demands of exercise. In both scenarios, insufficient energy remains available to support essential physiological functions, potentially leading to numerous adverse health consequences (24).

Two forms of LEA are recognized: adaptive and problematic (8). Adaptive LEA represents a short-term, mild reduction in energy availability that may occur during planned increases in training load or brief dietary restriction and does not result in long-term harmful effects. In such cases, the body can temporarily redistribute available energy to preserve function without major negative consequences. In contrast, problematic LEA refers to prolonged, severe, or frequently recurring energy imbalance that leads to persistent and harmful dysfunction across multiple physiological systems.

Chronic exposure to problematic LEA is the primary driver of REDs and is associated with disturbances in metabolism, hormonal balance, immune function, bone mineral density, reproductive function, cardiovascular health, and psychological well-being. Research indicates that individual physiological systems may respond differently to the duration, intensity, and frequency of LEA, resulting in effects that range from mild to severe depending on factors such as sex, age, genetic predisposition, psychological profile, and baseline health status (1).

Of particular concern is the fact that LEA is often unrecognized or misinterpreted in sports practice. In some sports, its effects—such as temporary performance improvements associated with weight loss—may even be encouraged, further delaying identification and intervention. Consequently, a thorough understanding of LEA and its consequences is essential not only for protecting athlete health but also for ensuring sustainable athletic performance. The International Olympic Committee has explicitly emphasized the need for systematic monitoring of energy availability and education of healthcare professionals, coaches, and athletes regarding this frequently overlooked yet significant risk (8).

Although research suggests that optimal physiological function is generally supported when energy availability is at least 45 kcal/kg fat-free mass/day, substantial interindividual variability exists. This means that no single energy availability threshold uniformly affects all athletes in the same way, particularly with respect to sensitive physiological processes such as menstrual function (26).

SPECIFIC ENERGY REQUIREMENTS ACCORDING TO TRAINING TYPE

Athletes' energy requirements vary substantially depending on the volume and intensity of physical activity. According to Garber et al., individuals who train fewer than five times per week for 30–45 minutes per session do not exhibit markedly increased energy demands compared with the general population (27). For these individuals, a daily energy intake of approximately 25–35 kcal/kg body mass is generally sufficient.

Athletes engaging in moderate physical activity, such as training three times per week for 30–40 minutes, with an estimated energy expenditure of 200–400 kcal per session, can likewise meet their energy requirements with a daily intake of 25–35 kcal/kg body mass. Leutholtz and Kreider confirm that these athletes can adequately meet their nutritional needs through a balanced diet without the need for specific dietary interventions (28).

The situation changes considerably in elite athletes who perform high-intensity training five to six times per week, with training durations ranging from two to six hours per session. In this population, energy requirements increase exponentially, as exercise energy expenditure may reach 600–1,200 kcal per hour. Leutholtz and Kreider report that daily energy requirements in elite athletes may range from 50–80 kcal/kg body mass per day (28).

Extreme energy demands are observed in ultra-endurance athletes. For example, cyclists participating in the Tour de France may expend up to 12,000 kcal per day, corresponding to approximately 150–200 kcal/kg body mass in a cyclist weighing 60–80 kg. Similarly, in large athletes with body masses between 100 and 150 kg, daily energy requirements may range from 6,000 to 12,000 kcal, presenting a significant logistical challenge in achieving adequate energy intake (29).

RISK FACTORS FOR RELATIVE ENERGY DEFICIENCY IN SPORT IN FEMALE ATHLETES

Based on the most recent expert consensus of the International Olympic Committee on REDs, several complex and interrelated risk factors can be identified that significantly contribute to the development of this syndrome, which is characterized by both physiological and psychological dysfunctions (1). The central etiological mechanism is exposure to problematic LEA, which occurs when energy intake is insufficient to meet the body's energy demands following intensive exercise, leaving inadequate energy to support optimal function of essential physiological processes. This energy imbalance may result from intentional weight reduction strategies—such as attempts to improve power-to-weight ratio or meet sport-specific aesthetic demands—or from unintentional failure to adjust energy intake to increased training loads, which is common among athletes who do not adequately modify their nutrition in response to higher physical activity levels.

Recent research has also highlighted the specific role of low carbohydrate availability, which often coexists with LEA (30). Even when total energy intake appears adequate, insufficient carbohydrate availability may lead to specific physiological dysfunctions, including increased bone resorption, reduced bone formation, impaired immune response, and disrupted iron metabolism. Studies have demonstrated that carbohydrate deficiency negatively influences the development of clinical consequences associated with REDs, underscoring the need for careful management of this macronutrient group, particularly during periods of dietary restriction (30).

REDs frequently involves disordered eating behaviors that do not necessarily meet the diagnostic criteria for a clinical eating disorder but nevertheless significantly affect an athlete's health. These behaviors include food restriction, compulsive overeating, irregular eating patterns, excessive compensatory exercise, and the use of laxatives. Such behaviors often go unnoticed because they are frequently normalized within athletic environments as part of the training culture (8).

Psychological mechanisms represent another highly significant and prevalent risk factor. Athletes often display high levels of perfectionism, control, self-discipline, and intrinsic motivation to achieve performance goals, while simultaneously being exposed to strong external pressures from coaches, support staff, and sport cultures that idealize leanness and strict control of body composition. In addition, athletes may receive positive reinforcement—such as praise or improved performance outcomes—that further reinforces restrictive eating behaviors, thereby increasing the risk of REDs. Psychological consequences associated with REDs include depressive symptoms, anxiety, mood disturbances, reduced sleep quality, disturbed body image, dietary restriction, and exercise dependence. Difficulties with motivation, emotional instability, social withdrawal, and reduced ability to cope with nutritional pressures are also commonly observed (8).

The training and social environment in which an athlete operates also plays a critical role in the development of REDs. In many sports—particularly those emphasizing aesthetics, body weight, or endurance—there is a deeply ingrained culture of weight control that is often reinforced by coaches and, at times, healthcare professionals who may lack sufficient expertise or sensitivity regarding safe practice. Inappropriate body composition assessment practices, such as frequent measurements without clear clinical justification, can contribute to body dissatisfaction, disordered eating behaviors, and long-term psychological distress, especially in young athletes. Exposure to such pressures without adequate professional support is particularly risky and may serve as a trigger for the transition from adaptive to problematic LEA.

The type of sport and its specific demands significantly influence the risk of developing REDs. Sports that emphasize leanness, aesthetic appearance, or weight categories—such as gymnastics, figure skating, ballet, athletics, swimming, cycling, combat sports, and endurance disciplines—are associated with a markedly higher risk of REDs. In these environments, body weight is often directly linked to athletic success, encouraging athletes to control body mass through restrictive dieting, excessive training, or a combination of both. Such behaviors lead to a gradual reduction in energy availability, as energy intake fails to match increased energy expenditure, ultimately resulting in a state of chronic energy deficiency (8).

A particularly high-risk group includes sports in which aesthetic appearance is an integral component of performance evaluation, such as rhythmic gymnastics, figure skating, and ballet. In these disciplines, psychological and social pressures related to body appearance promote unrealistic expectations of leanness. Research indicates that female athletes in aesthetic sports are more than twice as likely to experience menstrual dysfunction and reduced bone mineral density compared with athletes whose performance is not directly linked to body appearance (5).

In weight-category sports such as judo, boxing, rowing, and wrestling, the risk of REDs is increased due to repeated cycles of rapid weight loss and regain prior to competition. These cycles are associated with hormonal disturbances, dehydration, and metabolic stress, which may have long-term negative effects on thyroid and reproductive hormone function.

In endurance sports such as running, triathlon, swimming, and cycling, REDs often develops gradually. Prolonged training sessions with high energy expenditure may result in athletes consistently expending more energy than they consume, leading to reduced energy availability. Athletes in these disciplines may not recognize early warning signs, as they often maintain stable body mass and high performance levels. Over time, however, symptoms such as fatigue, loss of muscle mass, increased injury incidence, and impaired immune function may emerge (8).

It is important to recognize that sport type influences not only physiological demands but also the cultural and psychological factors within the sporting environment. In certain disciplines, leanness is idealized, and coaches, judges, or peers may indirectly reinforce behaviors that promote energy deficiency. The interaction between motivation, self-perception, and athletic identity can create an environment in which athletes overemphasize body weight while underestimating health consequences. These practices are particularly concerning in young female athletes, whose hormonal systems are still developing and who require adequate energy intake to support growth, pubertal development, and bone mineralization. Energy deficiency during this critical period may result in long-term consequences such as amenorrhea, delayed menarche, and reduced bone mineral density, with lasting effects on health into adulthood (8).

Individual factors also play a significant role in the risk of developing REDs. These include sex, age, genetic predisposition, psychological profile, and previous experiences with disordered eating or body dysmorphia. In female athletes, the consequences of LEA—such as menstrual cycle disturbances—tend to manifest earlier, as the reproductive system is highly sensitive to reductions in energy availability. Even minor changes in leptin and estrogen levels can suppress the hypothalamic–pituitary–ovarian axis (31). Male athletes often do not exhibit such overt symptoms; however, they may experience other manifestations, including reduced testosterone concentrations, loss of muscle mass, decreased bone mineral density, and reduced libido.

Age represents an additional important risk factor. In adolescents who are still developing, energy deficiency is particularly harmful because the body must simultaneously meet the demands of growth, hormonal maturation, and athletic training. During this stage, energy requirements are substantially higher than in adults, making adolescent athletes more vulnerable to insufficient nutrient and energy intake. Consequences may include delayed puberty, reduced bone mineral density, slower recovery from injury, and compromised attainment of peak height (8).

Beyond biological and physical factors, psychological characteristics play a critical role. Traits such as perfectionism, high self-criticism, anxiety, and low self-esteem are associated with an increased risk of disordered eating and related energy imbalances. Pressure from coaches, media, and social networks—where idealized body images are often promoted—may further exacerbate body dissatisfaction and promote restrictive eating behaviors. Among female athletes with pronounced perfectionistic traits, the risk of developing REDs is reported to be three times higher than in athletes who maintain a balanced relationship with nutrition and body image (32).

IDENTIFICATION OF RELATIVE ENERGY DEFICIENCY IN SPORT

The identification of REDs requires a careful and multidisciplinary approach, as it is a complex and often concealed condition that develops gradually and involves multiple physiological and psychological indicators. The International Olympic Committee has developed a structured screening and diagnostic tool known as the IOC REDs Clinical Assessment Tool – Version 2 (IOC REDs CAT2). This tool is designed to support evidence-based identification, risk stratification, and management of athletes with suspected REDs (1).

REDs manifests through a wide range of symptoms affecting multiple body systems, including the reproductive system (menstrual disturbances, reduced testosterone), skeletal system (osteopenia, osteoporosis, stress fractures), metabolic and endocrine systems (reduced triiodothyronine [T3], elevated cortisol, decreased resting metabolic rate), immune system (increased susceptibility to infections), hematological system (anemia, reduced ferritin levels), and psychological functioning (depression, anxiety, disordered eating, exercise dependence). Early signs are often subtle and may be overlooked or misinterpreted by athletes and coaches as normal responses to intensive training. Consequently, systematic screening is essential and should be based on clinical judgment, laboratory testing, sport-specific medical history, and behavioral indicators.

The IOC REDs CAT2 plays a central role in the screening and identification of at-risk individuals, assessment of condition severity, and treatment planning. The tool is implemented through a three-step clinical process (1).

The first step focuses on screening and early identification of at-risk athletes through the collection of basic demographic and medical data, clinical interviews, and the use of validated questionnaires to detect disordered eating behaviors, menstrual disturbances, sudden changes in body composition, or alterations in training habits. This phase enables early recognition of individuals who may be at increased risk for REDs.

The second step involves the evaluation of predefined clinical indicators categorized into primary, secondary, and potential indicators. Primary indicators include conditions such as amenorrhea, diagnosed eating disorders, and recurrent stress fractures. Secondary indicators encompass low bone mineral density, biological markers of hormonal imbalance, and reduced resting metabolic rate. Potential indicators include dietary behaviors, psychological profile, and social or environmental pressures. These indicators assist the clinical team in classifying athletes into low-, moderate-, or high-risk categories for REDs. Each indicator carries a specific score that contributes to the overall risk assessment.

The final step consists of treatment planning. Healthcare professionals, in collaboration with coaches, make decisions regarding training and competition restrictions and develop an individualized treatment and monitoring plan. The IOC REDs CAT2 serves as an important diagnostic and therapeutic framework that enables standardized clinical management. In addition, the repeated use of clinical indicators over time is encouraged to monitor treatment effectiveness and guide return-to-training decisions.

PHYSIOLOGICAL EFFECTS ON THE BODY

One of the primary indicators of LEA is functional hypothalamic amenorrhea, a condition in which women lose their menstrual cycle as a result of physiological adaptations to stress, undernutrition, or excessive physical exercise (8). LEA induces numerous hormonal changes that significantly affect the function of multiple physiological systems. In a state of energy deficiency, circulating levels of leptin, a hormone involved in satiety regulation and a key modulator of the reproductive axis, decrease first. Leptin stimulates the release of gonadotropin-releasing hormone (GnRH), thereby influencing the secretion of luteinizing hormone (LH) and follicle-stimulating hormone (FSH). When leptin concentrations fall below a critical threshold (approximately 30 kcal/kg fat-free mass per day), this stimulatory effect is reduced, leading to suppression of the hypothalamic–pituitary–gonadal axis.

Simultaneously, levels of ghrelin, an appetite-stimulating hormone, increase under conditions of LEA. Elevated ghrelin concentrations further inhibit the secretion of GnRH and LH, contributing to reproductive dysfunction, including hypogonadism. In addition, insulin levels decrease, and because insulin normally supports GnRH secretion, its reduction further impairs reproductive axis function. A key consequence of these hormonal alterations is a reduction in estradiol levels, resulting in a state of hypoestrogenism. Estrogen deficiency affects numerous physiological processes, particularly bone health and cardiovascular function. LEA also influences the thyroid axis, leading to reduced concentrations of triiodothyronine (T3), which contributes to a decrease in basal metabolic rate and represents a metabolic adaptation aimed at conserving energy (33).

A particularly important consequence of LEA is its effect on the menstrual cycle. Energy deficiency suppresses GnRH secretion, leading to reduced pulsatile release of LH and, consequently, decreased ovulatory frequency. These alterations result in various menstrual disturbances, most commonly luteal phase deficiency, anovulatory cycles, oligomenorrhea, and amenorrhea. Research indicates that approximately 50% of female athletes experience subclinical menstrual disturbances, while about one-third have clinically diagnosed amenorrhea. Reduced FSH secretion further impairs follicular maturation, leading to more pronounced decreases in estrogen and progesterone levels. Collectively, these changes have a substantial impact on reproductive health. Importantly, menstrual disturbances caused by LEA are largely reversible, as restoration of adequate energy balance can re-establish normal cyclic and menstrual function in most cases (8).

LEA triggers a complex endocrine response affecting the reproductive, metabolic, cardiovascular, immune, and skeletal systems. Hormonal alterations—including reductions in leptin, insulin, and estradiol, alongside elevations in ghrelin—disrupt the hypothalamic–pituitary–gonadal axis and manifest clinically as menstrual dysfunction (34). These disturbances secondarily impair bone mineral density and increase the risk of osteoporosis and cardiovascular complications (8).

Although many physiological consequences of LEA are reversible with appropriate nutritional and behavioral interventions, certain effects—particularly loss of bone mass—may be long-lasting or even permanent. Bone health and the incidence of stress fractures are closely linked to chronic energy deficiency. Bone metabolism is highly sensitive to energy balance and hormonal regulation; therefore, LEA leads to decreased bone mineral density, increased bone resorption, and reduced bone formation. In women, this manifests primarily as increased bone catabolism, substantially elevating the long-term risk of osteoporosis. Bone loss is especially prevalent in sports that emphasize low body mass, such as cycling, rowing, and long-distance running, where prolonged periods of energy deficiency are common.

Experimental studies have demonstrated that diet-induced LEA reduces bone formation, with more pronounced effects observed under low-carbohydrate dietary conditions (35). Adequate energy intake—particularly when supported by sufficient carbohydrate availability—can significantly mitigate adverse effects on bone metabolism. In addition to macronutrients, micronutrients such as vitamin D, calcium, and iron play a crucial role, alongside hormonal adaptations involving reductions in leptin, sex steroids, and growth hormone. Epidemiological data indicate a high incidence of stress fractures in both athletic and military populations, with women being at greater risk than men (36).

The most commonly affected sites include the tibia, metatarsal and tarsal bones, as well as the femur and pelvis. For this reason, early recognition of signs of LEA is of critical importance, particularly in female athletes, and timely intervention is essential. Within this context, the physiotherapist plays an important role as part of the interdisciplinary healthcare team (33).

The gastrointestinal effects of REDs encompass a wide spectrum of disturbances, ranging from functional symptoms to structural gastrointestinal impairments. Under normal physiological conditions, blood flow is redistributed toward active skeletal muscles during exercise, resulting in reduced perfusion of the gastrointestinal tract. During short-term exercise, the body typically adapts without major consequences; however, in the presence of chronic energy deficiency, more severe dysfunctions may develop. Studies have shown that athletes with LEA experience gastrointestinal symptoms more frequently, including delayed gastric emptying, constipation, bloating, and impaired sphincter control. Over time, these disturbances may compromise recovery and reduce the ability to adapt to training.

Similar gastrointestinal issues have also been observed in female military personnel, who are often exposed to a combination of high physical demands, energy deficiency, and environmental stressors. Reported conditions include chronic abdominal pain, irritable bowel syndrome, and diarrhea. Although the direct relationship between these symptoms and REDs has not yet been fully elucidated, existing evidence suggests a meaningful association between energy status and gastrointestinal health (37).

In addition to hormonal effects, the immunological consequences of REDs warrant particular attention. Chronic energy restriction reduces leukocyte functional activity, especially that of T lymphocytes and natural killer (NK) cells, leading to an increased incidence of upper respiratory tract infections and delayed wound healing (3). It has been reported that female athletes with LEA experience up to 30% more infections compared with those with adequate energy intake (2).

Psychological mechanisms also play a significant role, particularly disordered eating behaviors, perfectionism, and exercise dependence. Berge et al. noted that female athletes often develop a combination of dietary restriction and compulsive exercise, which further exacerbates energy imbalance (38). This state is frequently accompanied by symptoms of anxiety, social withdrawal, and depressive episodes, highlighting the need for comprehensive management that includes psychological or psychiatric support.

REDs affects not only physiological performance but also cognitive function. Energy deficiency impairs brain function, leading to reduced concentration, impaired decision-making, and diminished motor coordination, thereby increasing the risk of injury (5). Sleep disturbances are also common and further compromise recovery while exacerbating fatigue.

Rather than presenting as isolated impairments, REDs is characterized by interconnected dysfunction across multiple systems. Hormonal alterations—particularly reduced gonadotropin secretion—affect reproductive function and bone density, resulting in menstrual disturbances and osteopenia. These changes further impair calcium metabolism, increasing the risk of stress fractures. Consequently, the neuromuscular system is also affected; reduced protein synthesis and limited energy substrate availability lead to decreased contractile strength and impaired muscle recovery (39).

At the cardiovascular level, adaptive responses such as bradycardia and hypotension reflect reduced metabolic activity and an attempt to conserve energy. At the same time, alterations in lipid metabolism and elevated cortisol levels may contribute to dyslipidemia, illustrating the complex balance between physiological adaptation and increased health risk (3). The interaction between immune and psychological responses further underscores the systemic nature of REDs. Energy deficiency leads to reduced leptin levels, which not only regulate metabolism but also influence immune function and central nervous system activity. The result is increased susceptibility to infection and mood disturbances such as anxiety and irritability.

These manifestations are often not recognized as components of a single syndrome and are instead addressed in isolation, delaying comprehensive management (38). REDsore be understood not as a collection of independent symptoms, but as a dynamic state of systemic imbalance, in which dysfunction in one system triggers a cascade of effects in others. This perspective is crucial for clinical practice, as it directs healthcare professionals to identify patterns of interconnected signs, rather than focusing solely on individual clinical indicators.

Physiotherapists play a particularly important role in this process, as they are often the first professionals to encounter female athletes presenting with early warning signs such as impaired recovery, recurrent injuries, and changes in perceived energy levels. Understanding the systemic interactions underlying REDs enables physiotherapists to recognize emerging patterns early and to facilitate timely referral to appropriate specialists, thereby contributing to more effective prevention and management strategies.

STAGES OF RELATIVE ENERGY DEFICIENCY IN SPORT

The staging of REDs enables clinicians to assess the extent of metabolic, hormonal, and psychological alterations associated with LEA. Such classification is highly relevant in clinical practice, as female athletes often continue to train and compete despite already impaired physiological homeostasis. In most cases, energy deficiency develops gradually and remains unnoticed; therefore, understanding the individual stages is essential for early intervention and prevention of long-term consequences. Based on the severity of REDs, female athletes are classified into four categories (1).

Green Stage (Low Risk)

In the initial green stage, the body maintains stable internal balance despite demanding training loads. Energy intake is sufficient to support all essential metabolic functions, muscle and bone tissue repair, and normal hormonal activity. Athletes at this stage demonstrate high performance capacity, effective recovery, and stable psychological well-being. A regular menstrual cycle reflects appropriate function of the hypothalamic–pituitary–ovarian axis and represents one of the most reliable physiological indicators of adequate energy availability in women.

Bone mineral density is normal, with no signs of stress-related microfractures. Metabolic efficiency is preserved, thyroid hormone and insulin concentrations remain optimal, and immune function is intact. Although this stage is considered safe, it also has preventive value, emphasizing the importance of regular monitoring of dietary intake, body composition, menstrual cyclicity, and subjective well-being. Early detection of deviations at this stage allows prevention of progression to the yellow stage, where physiological balance begins to deteriorate.

Yellow Stage (Moderate Risk)

The yellow stage marks the onset of physiological adaptations to reduced energy availability. To protect against further energy loss, the body begins to downregulate energy-intensive processes, including reproductive function, growth, and bone tissue synthesis. Circulating levels of triiodothyronine (T3) gradually decline, while cortisol and adrenaline concentrations increase, indicating chronic activation of the stress response.

The menstrual cycle becomes irregular or anovulatory, meaning that ovulation may still occur but with reduced hormonal amplitude. Bone mineral density begins to decline, although it often remains within normal limits at this stage. Athletes commonly report increased fatigue, mood fluctuations, reduced tolerance to high training loads, and impaired recovery.

Competitive readiness may still be maintained during this phase; however, adjustments in nutrition and training planning are required. Key interventions include increasing overall energy intake, ensuring adequate carbohydrate and protein availability, and allowing sufficient recovery periods. The yellow phase often persists for several months and represents a critical window during which timely action can prevent progression to more severe clinical consequences.

Orange Stage (High Risk)

With further progression of energy deficiency, the body enters the orange stage, in which disturbances are clearly expressed and objectively measurable. Prolonged energy restriction suppresses reproductive axis function, leading to secondary amenorrhea, defined as the complete absence of menstruation for three or more consecutive cycles.

Levels of sex hormones—particularly estradiol and progesterone—decline markedly, negatively affecting bone mineral density, muscle protein synthesis, and psychological stability. Alterations in thyroid hormone concentrations reflect an adaptive hypothyroid state, while elevated cortisol accelerates muscle catabolism. Clinically, these hormonal changes manifest as reduced endurance capacity, diminished explosive strength, prolonged recovery time, and a significantly increased risk of injury.

Psychological disturbances frequently accompany the orange stage, including anxiety, burnout, feelings of guilt associated with food intake, and fear of weight gain. In some cases, eating disorders begin to emerge, further exacerbating energy imbalance. Sleep disturbances, gastrointestinal complaints, recurrent infections, and persistent muscle and bone pain that do not resolve with rest are also common. At this stage, regular medical follow-up, hormonal and bone assessments, and close collaboration with a sports dietitian and psychologist are strongly recommended. Training typically needs to be reduced, particularly in volume and intensity, with emphasis placed on recovery-oriented activities and restoration of energy stores.

Red Stage (Very High Risk)

The red stage represents the final and most severe phase of the syndrome, in which the athlete's health is directly endangered. In this state, the body enters a pronounced energy-conservation mode, with widespread slowing of metabolic processes to preserve basic vital functions. Energy availability is extremely low and the condition has usually persisted for a prolonged period, resulting in extensive dysfunction across multiple organ systems.

The hormonal profile reflects severe endocrine disruption, characterized by markedly reduced concentrations of estrogen, testosterone, triiodothyronine (T3), and growth hormone, alongside substantially elevated cortisol levels. These alterations lead to muscle catabolism, loss of body mass, reduced contractile strength, and profound fatigue. Bone mineral density is often markedly reduced, resulting in osteopenia or osteoporosis and frequent stress fractures, particularly involving the pelvic ring, tibia, or foot.

The cardiovascular system is compromised, with manifestations such as bradycardia, hypotension, cardiac rhythm disturbances, and orthostatic dizziness. Additional features include gastrointestinal dysfunction, cold intolerance, dry skin, hair loss, and brittle nails. From a psychological perspective, clinical depression, severe anxiety, or complete loss of motivation is frequently present. In extreme cases, severe eating disorders, such as anorexia nervosa or bulimia nervosa, may develop.

At the red stage, all training is contraindicated. Immediate medical intervention is required, often in a hospital setting, where vital parameters are closely monitored and energy intake is gradually increased. Restoration of normal hormonal function may take months or even years, and some consequences—such as loss of bone mineral density or persistent amenorrhea—may not fully resolve. Effective treatment must include both physical and psychological rehabilitation, as recovery depends on the athlete's ability to re-establish a healthy relationship with food, body image, and exercise.

RECOGNIZING SUBCLINICAL AND CLINICAL RELATIVE ENERGY DEFICIENCY IN SPORT IN FEMALE ATHLETES

The classification of female athletes according to the stages of REDs represents more than a diagnostic framework; it provides a means of understanding the complex interaction between energy intake, physiological function, and athletic performance. The purpose of this classification is not only to prevent severe health consequences but also to preserve long-term athletic careers. It is essential that the multidisciplinary team working with an athlete is able to recognize the earliest signs of energy deficiency and intervene before irreversible changes occur. Timely intervention and comprehensive management allow athletes to return safely to optimal training and competitive performance without compromising their health.

It is important to emphasize that REDs can develop even in athletes whose body mass and external appearance do not suggest undernutrition (4). Many female athletes with REDs maintain an apparently stable body mass, and their body fat percentage often remains above 21%, which is considered the lower physiological limit of acceptable fat mass in women of reproductive age. This threshold represents a critical level below which hormonal alterations affecting gonadotropin secretion, estrogen production, and hypothalamic function typically occur (4). However, even when body composition falls within normal ranges, substantial energy deficiency may still be present if energy intake is chronically lower than energy expenditure.

The preservation of body fat above 21% often leads to the misconception that the athlete is metabolically healthy. In reality, under such conditions the body activates protective mechanisms aimed at maintaining vital functions and safeguarding internal organs. One such mechanism is the redistribution of adipose tissue, whereby fat stores are preserved or even increased in the abdominal region and around vital organs, while energy supply to peripheral processes—such as growth, tissue repair, reproductive function, and thermoregulation—is reduced. As a result, an athlete may appear physically healthy, while metabolic, endocrine, and immune functions are already significantly compromised.

This state is frequently accompanied by disturbances in thermoregulation, reduced basal body temperature, and persistent fatigue, reflecting suppressed thyroid hormone activity, particularly reduced triiodothyronine (T3). In addition, synthesis of growth hormone and insulin-like growth factor 1 (IGF-1) is diminished, leading to impaired tissue repair and delayed recovery following training (34). Immune function may also be compromised, manifesting as increased susceptibility to respiratory infections and delayed wound healing.

Hormonal imbalance further affects bone metabolism. Reduced concentrations of estrogen and leptin decrease osteoblast activity, thereby increasing the long-term risk of osteopenia and stress fractures—even in women with apparently normal body fat levels (36). Thus, the maintenance of body fat above 21% represents an adaptive survival strategy aimed at protecting vital structures rather than an indicator of metabolic health. In the context of REDs, this phenomenon is particularly misleading, as it may obscure underlying energy deficiency and delay diagnosis.

Female athletes who maintain stable body mass but exhibit signs of hormonal imbalance, chronic fatigue, or menstrual irregularities therefore constitute a particularly vulnerable group, as they do not conform to the stereotypical image of an energy-depleted individual. Recognizing this presentation is crucial for early identification and effective prevention of long-term health and performance consequences associated with REDs.

Stress also plays a crucial role in understanding this phenomenon, as it acts as an additional metabolic and hormonal stressor (8). Chronically elevated cortisol levels—characteristic of prolonged physical or psychological stress—further reduce energy availability by accelerating muscle protein breakdown and suppressing reproductive and immune function. When combined with insufficient energy intake, stress can hasten the transition from a subclinical to a clinical form of REDs, leading to more pronounced hormonal and psychological consequences.

In such cases, blood analysis and hormonal profiling are essential for timely identification of underlying disturbances. Reduced concentrations of triiodothyronine (T3), estradiol, ferritin, and insulin-like growth factor 1 (IGF-1), together with elevated cortisol and urea levels, often indicate the presence of energy deficiency—even when basic indicators such as body mass or body fat percentage remain within normal ranges. Diagnostic procedures must therefore adopt a comprehensive approach, rather than relying solely on measures of body composition.

Female athletes who maintain stable body mass and body fat percentages above 21%, yet exhibit signs of hormonal imbalance, menstrual irregularities, chronic fatigue, or recurrent injuries, require particular clinical attention. This group is frequently underdiagnosed or misclassified, as traditional markers of physical fitness fail to reveal the underlying energy deficit. In such cases, early recognition and intervention are critical to preventing long-term consequences such as reduced bone mineral density, amenorrhea, and disturbances in psychological well-being (8).

Taken together, these findings clearly demonstrate that a body fat percentage above 21% does not necessarily indicate energy balance or hormonal health. In the context of REDs, this value does not provide protection against physiological dysfunction; rather, it represents only the lower physiological threshold at which the body can continue to function—often at the expense of other vital systems. For this reason, assessment of energy availability must consider not only body composition but also metabolic, hormonal, and psychological markers, which together provide a comprehensive picture of an athlete’s health status (5,8).

TREATMENT

The treatment of REDs must be comprehensive, long-term, and individualized, as it involves physiological, nutritional, hormonal, and psychological factors. The primary goal is restoration of energy balance, which requires achieving sufficient energy intake relative to daily expenditure and the gradual normalization of hormonal axis function and the menstrual cycle (1).

In the initial phase of treatment, it is essential to reduce training load while simultaneously increasing energy intake. According to recommendations from the International Olympic Committee, athletes with moderate to severe REDs should reduce training volume by 20–50% and progressively increase daily energy intake by approximately 300–600 kcal, targeting an energy availability of at least 45 kcal/kg fat-free mass (10). This gradual approach allows the body to adapt to increased energy intake without inducing metabolic stress and reduces the risk of relapse into disordered eating behaviors.

A critical component of treatment is the monitoring of recovery markers, including the resumption of the menstrual cycle, improvements in bone mineral density (assessed by DXA), normalization of leptin, estradiol, and triiodothyronine (T3) levels, and stabilization of body mass within a physiological range. In athletes with amenorrhea lasting longer than six months, supplementation with calcium (1,500 mg/day) and vitamin D (1,500–2,000 IU/day) is recommended to support bone metabolism (39). In more severe cases, short-term hormonal therapy may be considered, but only as an adjunct—not a substitute—for energy rehabilitation.

Assessment of bone mineral density plays an important diagnostic role in REDs, as the syndrome frequently leads to reduced bone density due to chronic energy deficiency and disrupted hormonal regulation. Decreased estrogen concentrations negatively affect bone metabolism by reducing bone formation and increasing bone resorption, thereby elevating the risk of osteopenia, osteoporosis, and stress fractures—often key clinical indicators of advanced REDs. For this reason, DXA is commonly used as an essential diagnostic tool when evaluating the impact of energy deficiency on bone health, particularly in athletes with menstrual disturbances or signs of LEA (36).

Because REDs often has a significant psychological component, treatment must include psychotherapeutic support. Cognitive-behavioral therapy is commonly employed to help athletes identify maladaptive eating behaviors, perfectionistic thought patterns, and excessive preoccupation with body image (38). The involvement of family members and the coaching environment is also important, as social pressures often contribute to the onset and persistence of the syndrome.

The role of the physiotherapist in the treatment process is particularly important. In addition to monitoring functional status and facilitating a gradual return to training, physiotherapists assess recovery and fatigue and educate athletes on appropriate balance between training load and recovery. Physiotherapists are often the first professionals to detect signs of overuse or declining performance and therefore must be familiar with the key diagnostic indicators of REDs and recognize patterns characteristic of energy deficiency.

In later stages of treatment, clinicians focus on a gradual return to training using the return-to-sport model developed by the International Olympic Committee. Health professionals continuously assess medical indicators, energy availability, and psychological readiness. Athletes are permitted to resume competitive participation only after meeting all criteria, including normalized body mass, restoration of the menstrual cycle, and stabilization of hormonal parameters (1).

If no meaningful improvement is observed after three to six months of energy rehabilitation, further endocrinological evaluation is recommended to exclude alternative causes of hypothalamic dysfunction. In cases of persistent amenorrhea, low-dose estrogen therapy may be introduced, but always in collaboration with a gynecologist and endocrinologist.

For athletes exhibiting signs of eating disorders, close collaboration among physicians, psychologists, dietitians, and physiotherapists is essential. This multidisciplinary approach not only accelerates recovery but also reduces the risk of relapse and long-term complications such as osteoporosis, depression, and impaired fertility (5).

In the final phase of treatment, athletes are educated on recognizing early warning signs of energy deficiency, appropriate nutritional planning, and the importance of recovery. Preventive strategies include regular monitoring of the menstrual cycle, body composition, and metabolic markers, as well as open communication within the sports support team.

Successful management of REDs is based on the principle that restoring energy balance is not merely a nutritional objective, but a process of comprehensive physical and psychological rehabilitation that requires patience, multidisciplinary support, and gradual re-establishment of trust in one’s body.

CONCLUSION

Relative Energy Deficiency in Sport is a complex, systemic condition that arises from prolonged low energy availability and affects multiple physiological and psychological systems simultaneously. In female athletes, REDs most commonly manifests through menstrual dysfunction, impaired bone health, reduced metabolic efficiency, increased injury risk, and psychological disturbances. Importantly, the syndrome may develop even in athletes with normal body mass and body fat percentage, making reliance on external appearance an unreliable diagnostic indicator.

This review highlights that REDs is not confined to elite sport, nor to athletes with overt eating disorders, but can emerge insidiously through cumulative training stress, inadequate nutritional strategies, psychological pressure, and sport-specific cultural norms that prioritize leanness. Endurance, aesthetic, and weight-category sports present the highest risk, particularly when early warning signs are overlooked or normalized within the training environment.

Early identification using validated tools such as the IOC REDs Clinical Assessment Tool (CAT2), combined with careful monitoring of hormonal, metabolic, and behavioral markers, is essential. Effective treatment requires a multidisciplinary approach focused on restoring energy availability, modifying training load, addressing psychological factors, and supporting long-term behavioral change. Nutritional rehabilitation remains the cornerstone of recovery, while pharmacological interventions should be considered only as adjunctive measures.

Physiotherapists occupy a central position in REDs management due to their close and continuous contact with athletes. Their role in recognizing early signs such as delayed recovery, recurrent injuries, and unexplained performance decline is critical for timely referral and prevention of long-term consequences.

Ultimately, successful prevention and management of REDs depend on shifting sports culture toward health-centered performance models, improving education among coaches and healthcare professionals, and promoting early, proactive intervention. Addressing REDs is not only essential for protecting athlete health but also for ensuring sustainable athletic careers and long-term well-being.

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