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RELATIVE ENERGY DEFICIENCY IN SPORT (RED-S/REDs) IN ATHLETES: A NARRATIVE REVIEW OF CLINICAL CONSEQUENCES, SCREENING, PREVENTION, AND DIGITAL HEALTH IMPLICATIONS

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ABSTRACT

Relative Energy Deficiency in Sport (REDs) is a clinical syndrome resulting from problematic low energy availability and associated with impaired physiological and psychological functioning in athletes. This narrative review synthesizes current evidence on the conceptual development of REDs, its multisystem consequences, screening and diagnosis, prevention, management, return-to-play considerations, and digital health implications. Literature was reviewed thematically, with priority given to International Olympic Committee consensus statements, clinical assessment tools, narrative and systematic reviews, and studies addressing low energy availability, endocrine and bone health, mental health, male and adolescent athletes, and athlete monitoring. Current evidence indicates that REDs may affect reproductive, skeletal, endocrine, metabolic, immunological, gastrointestinal, cardiovascular, hematological, psychological, and performance-related domains. Diagnosis remains challenging because symptoms are often nonspecific and no single biomarker confirms the condition. Assessment should therefore combine medical history, training load, nutritional intake, reproductive and bone health indicators, psychological screening, laboratory and imaging findings when indicated, and structured tools such as the IOC REDs CAT2. Management should focus on restoring adequate energy availability, adapting training load, treating medical complications, and providing psychological support when needed. Prevention requires coordinated action from athletes, coaches, parents, clinicians, and sport organizations. Digital tools may support early identification, but only when implemented within confidential, ethical, and athlete-centered systems.

KEYWORDS

Relative Energy Deficiency in Sport, Low Energy Availability, Athlete Health, Sports Medicine, Screening, Prevention

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1. Introduction

Sport is widely promoted as a route to health, resilience, social participation, and personal growth. Simultaneously, the structure of sport can create an environment where athletes can experience training demands, pressure to modify body composition, a relentless schedule and social norms that encourage a performance-focused ethic, but may not attend to indicators of physiological stress. In this context, RED-S, now referred to as REDs in current IOC terminology, has become one of the more significant and controversial areas within sports medicine at the present time. REDs is not simply a problem of being thin, dieting, or losing weight. It is a collection of physiological and psychological dysfunctions secondary to pathological low energy availability (LEA), defined as not having enough dietary energy remaining after exercise energy expenditure to fuel the physiological and psychological processes of health, adaptation, and performance (Loucks et al., 2011; Mountjoy et al., 2023).

The term RED-S was coined by the IOC in 2014 to evolve beyond the more restrictive Female Athlete Triad model (Mountjoy et al., 2014). The Triad is clinically relevant and indicates that these conditions - low energy availability, menstrual dysfunction and low bone mineral density - occur together in physically active girls and women (De Souza et al., 2014). Clinical and experimental observations however showed that energy deficit can influence a range of physiological systems other than the reproductive and the skeletal system and can have both clinically significant health and performance consequences for male athletes as well. The IOC then recommended a broader model covering metabolic, endocrine, hematological, immunological, gastrointestinal, cardiovascular, psychological, and performance-related outcomes (Mountjoy et al., 2014, 2018, 2023).

The IOC updated its definition in 2023 and highlighted that there is a continuum of low energy availability from beneficial to harmful. Short periods of reduced energy balance are possible in sport, and are not always necessarily detrimental if they are short, planned and recovered from. Problematic Low Energy Availability (LEA) is defined as being intense, repeated, or of a chronic nature and where impaired recovery and resultant negative health or performance consequences exist (Burke et al., 2023; Mountjoy et al., 2023). This is relevant as it prevents any short-term disparity between energy consumed and expended from being defined as a "disease" and allows for clinically dangerous amounts of persistent or recurrent negative energy balance.

REDs is relevant to a diverse range of sporting populations. Although it is often discussed in relation to endurance, aesthetic, leanness, and weight-category sports, it can also occur in team, para, recreational, adolescent, and military-style training settings. Athletes may develop REDs because of conscious dietary restriction, disordered eating, eating disorders, weight-cutting practices, appetite suppression, gastrointestinal problems, limited food access during travel, insufficient nutritional knowledge, cultural pressure, or a mismatch between energy intake and training load (Logue et al., 2020; Wasserfurth et al., 2020). All of this matters because treatment of LEA requires not just telling the athlete to eat more, but understanding the source and sustaining factors of the condition.

REDs may present with nonspecific clinical signs and their symptoms are challenging to diagnose early. A patient may report fatigue, frequent infection, poor sleep, irritability, gastrointestinal discomfort, low mood, impaired training response, menstrual irregularity, low libido, or recurrent bone stress injury which are attributed to heavy training, stress or demands of competition. Within some sport cultures, there is a pay-off for enduring discomfort, and athletes may be reluctant to report symptoms or injuries that could jeopardize selection or competition opportunities. Additionally, coaches may not have education on the health implications of under-fueling, menstrual dysfunction, and chronic fatigue. Therefore, REDs is more than a medical condition, it is a sport-system problem that arises from interactions among communication practices, governance structures, data processes, and attitudes toward body weight and performance (Mountjoy et al., 2023; Torstveit et al., 2023).

The objective of this review is to integrate current knowledge regarding REDs in athletes and focuses on definitions, mechanisms, risk factors, health outcomes, screening and diagnosis, prevention and management, and future directions for the utilization of digital health. The report has been written as a review article for an interdisciplinary readership and consequently addresses both medical and social dimensions. In essence the central contention is that REDs cannot be addressed solely through individual clinical management; they demand athlete-centered care, multidisciplinary teamwork, preventive sport policy and a discerning stance regarding technologies which may aid health monitoring or enhance the distressing pressures of health surveillance.

2. Methodology

This article was designed as a narrative review. A narrative approach was selected because Relative Energy Deficiency in Sport (REDs) is a broad and evolving clinical and socio-organizational issue that includes physiological, nutritional, psychological, behavioral, technological, and sport-system dimensions. The aim was not to conduct a quantitative meta-analysis, but to synthesize current evidence and expert consensus in order to provide an integrative overview for clinicians, researchers, coaches, sport organizations, and interdisciplinary readers.

A targeted literature search was conducted using PubMed, Scopus, Web of Science, and Google Scholar. The search focused on publications concerning Relative Energy Deficiency in Sport, low energy availability, the Female Athlete Triad, athlete health, endocrine and bone consequences, mental health, screening, clinical assessment, prevention, return-to-play decisions, and digital health monitoring in sport. The following terms and combinations were used: "Relative Energy Deficiency in Sport", "RED-S", "REDs", "low energy availability", "Female Athlete Triad", "athlete health", "screening", "LEAF-Q", "IOC REDs CAT2", "bone stress injury", "endocrine function", "male athletes", "adolescent athletes", "mental health", "sports nutrition", "return to play", "digital health", "wearable devices", and "athlete monitoring".

Priority was given to peer-reviewed journal articles, International Olympic Committee consensus statements, clinical assessment tools, methodological papers, systematic reviews, and relevant narrative reviews. Particular attention was paid to the IOC consensus statements published in 2014, 2018, and 2023, the IOC REDs Clinical Assessment Tool version 2, and associated subgroup publications addressing the physiological model of REDs, clinical assessment, prevention, mental health, and methodological challenges. Studies addressing low energy availability, endocrine outcomes, bone health, female and male athletes, adolescent athletes, screening instruments, and performance implications were also included.

Publications were considered eligible when they addressed at least one of the following areas: the definition or conceptual development of REDs; mechanisms and consequences of low energy availability; epidemiology and risk factors; clinical presentation; screening and diagnostic approaches; prevention and management strategies; return-to-play considerations; psychological or social determinants; or the use of digital technologies in athlete monitoring. Articles were excluded when they were not directly related to REDs, low energy availability, or athlete health, when they focused exclusively on non-athletic populations, or when they provided insufficient relevance to the aims of this review. Because terminology has changed over time, both "RED-S" and "REDs" were used as search terms. In the manuscript, "REDs" is used to reflect the current IOC terminology, while "RED-S" is retained when referring to earlier literature or historical terminology.

The literature was analyzed thematically rather than statistically. Selected sources were grouped into major domains: conceptual development from the Female Athlete Triad to REDs; definition and measurement of low energy availability; risk groups and epidemiology; multisystem clinical consequences; screening and diagnosis; management and return-to-play; prevention; digital health and ethical considerations; special populations; and research gaps. Evidence from clinical, physiological, psychological, and socio-organizational perspectives was integrated to reflect the multidimensional nature of REDs.

Several limitations should be acknowledged. This review was narrative rather than systematic and therefore did not include formal risk-of-bias assessment, standardized study selection procedures, or quantitative pooling of results. The REDs literature also remains heterogeneous, with differences in definitions, screening tools, study populations, and outcome measures. No single diagnostic biomarker confirms REDs, and many studies rely on surrogate indicators such as menstrual dysfunction, hormonal changes, bone stress injury, dietary restriction, or performance decline. For these reasons, the review emphasizes multidimensional clinical reasoning that combines history, training load, nutritional intake, reproductive health, injury history, psychological status, laboratory and imaging findings when indicated, performance trends, and sport-specific context.

3. Results / Narrative Synthesis

The reviewed literature was synthesized into several thematic areas reflecting the multidimensional nature of Relative Energy Deficiency in Sport (REDs). The evidence indicates that REDs has developed from the narrower Female Athlete Triad model into a broader framework that includes athletes of different sexes, ages, performance levels, and sport types. Across the literature, low energy availability is consistently identified as the central mechanism, although its measurement remains challenging in applied sport settings.

The narrative synthesis identified several recurring domains: conceptual development of REDs; definition and assessment of low energy availability; epidemiology and risk groups; multisystem physiological and psychological consequences; clinical presentation and red flags; screening and diagnosis; management and return-to-play; prevention at athlete, coach, family, clinical, and organizational levels; digital health and ethical considerations; and special populations. These themes are presented in the following subsections.

Overall, the literature suggests that REDs should not be understood only as an individual nutritional problem. It is also shaped by training load, sport culture, body composition pressures, access to food and professional support, coach behavior, organizational policies, and the use of monitoring technologies. For this reason, the findings are organized thematically to integrate clinical, psychological, social, and technological perspectives.

3.1 Conceptual Development: From the Female Athlete Triad to REDs

The Female Athlete Triad gave rise to current views on sport-specific energy deficiency. Each of the three components - low energy availability, menstrual dysfunction, and low bone mineral density - showed how serious medical consequences may occur when energy expenditure exceeds energy intake (De Souza et al., 2014). The Triad gained importance in its attempt to debunk the notion that menstrual irregularity in athletes was an innocent side effect of training and that menstrual disturbance could be an indicator of an abnormal endocrine profile and skeletal danger.

However, the limitations of the Triad model were clear. This model had predominantly been tested on female athletes and concentrated most on the reproductive and skeletal outcomes. Clinically, it was also noticed that low energy availability may impact many other systems including metabolic rate, endocrine axes, hematological status, immune function, gastrointestinal function, cardiovascular health, and psychological well-being. The Triad also provided inadequate coverage of performance outcomes, males, athletes with a disability, or those competing outside of traditional endurance or aesthetic sports. These limitations led the IOC to propose "Relative Energy Deficiency in Sport" in 2014 (Mountjoy et al., 2014).

In 2014, the IOC consensus statement on RED-S established it as 'a condition of impaired physiological function due to relative energy deficiency' which impacts on aspects such as the metabolism, menstruation, bone, immunity, protein synthesis and cardiorespiratory health (Mountjoy et al., 2014). The 2018 update broadened the evidence base, and importantly it is recognized that athletes of both sexes are affected, though the presentation will be different between sexes, age groups, sports and athletes (Mountjoy et al. 2018). The 2023 IOC consensus statement clarified the terminology and distinguished more precisely between adaptable and problematic LEA (Mountjoy et al., 2023).

This represents an important evolutionary shift that is also medically significant, as the earlier terminology could imply that any reduction in energy availability was pathological. In reality, periods of lower availability are occasionally encountered in athletes during deliberate phases of training and competition without detrimental consequences, provided they are brief and followed by sufficient recovery. The present approach takes into account the following factors of exposure: magnitude, duration, frequency, source, timing, recovery. A single episode of acute energy restriction during a controlled training session, as an example, is unlike that associated with chronic restriction due to body dissatisfaction, fear of weight gain or frequent rapid weight cycling (Burke et al., 2023).

This evolution from the Triad to REDs illustrates a broader evolution of thought in sports medicine. Athlete health is now perceived as multifactorial and embedded in systems. A cyclist experiencing chronic illness and testosterone deficiency, an amenorrheic dancer experiencing multiple stress fractures, a fatigued iron-deficient runner, and a chronically dieting combat athlete may all suffer from the same underlying physiological mechanism (insufficient energy availability) despite presenting with unique syndromes. The REDs framework helps clinicians recognize connections between symptoms and avoid fragmented symptom management.

At the same time, the REDs model has generated debate. Several authors have suggested that the operationalization of the syndrome is challenging due to broad diagnostic criteria and multiple etiological mechanisms. Such criticisms can also be helpful for promoting methodological thoroughness and avoiding overdiagnosis. Despite not having one marker, the syndrome does have clinical relevance. Syndromic reasoning is applicable for the management of numerous medical conditions where biological systems interact and where signs and symptoms develop sequentially over time. REDs should be seen as a clinically applicable concept that still needs research method optimization, validation and population-specific thresholds (Ackerman et al., 2023; Stellingwerff et al., 2023).

3.2 Low Energy Availability: Definition, Measurement, and Practical Challenges

Energy availability is conventionally defined as dietary energy intake minus exercise energy expenditure, expressed relative to fat-free mass. It reflects the energy remaining for physiological processes such as reproductive function, bone remodeling, immune defense, thermoregulation, protein synthesis, endocrine signaling, recovery, and psychological functioning after the energetic cost of exercise has been accounted for (Loucks et al., 2011). This concept differs from energy balance, which compares total intake with total expenditure and is often inferred from changes in body mass. A stable body weight does not exclude REDs, because the body may compensate for insufficient energy availability by downregulating resting metabolic rate, reproductive function, or other processes.

In research settings, energy availability has often been described using thresholds expressed as kilocalories per kilogram of fat-free mass per day. In female athletes, values below approximately 30 kcal/kg fat-free mass/day have frequently been associated with low energy availability, whereas around 45 kcal/kg fat-free mass/day has often been discussed as adequate. These values should not be treated as universal clinical cut-offs for every athlete. Individual responses vary, and thresholds for male athletes, adolescents, para-athletes, and different sporting contexts remain less clearly defined (Mountjoy et al., 2023; Stellingwerff et al., 2023).

Accurate measurement is difficult outside controlled laboratory conditions. Dietary records may underestimate intake because athletes forget snacks, misjudge portion sizes, change eating behavior while recording, or omit drinks and supplements. Exercise energy expenditure is also difficult to estimate precisely, particularly when wearable devices or prediction equations are used across different sports and intensities. Fat-free mass estimates vary by method, and small errors in each component can substantially distort the final energy availability calculation (Ackerman et al., 2023; Logue et al., 2020).

For this reason, clinicians often use proxy indicators rather than relying solely on calculated energy availability. Relevant indicators include rapid weight loss, restrictive eating, missed meals, menstrual dysfunction, low libido, reduced morning erections, low bone mineral density, recurrent bone stress injury, endocrine abnormalities, reduced resting metabolic rate, iron deficiency, gastrointestinal complaints, fatigue, recurrent illness, psychological distress, and unexpected performance decline. These indicators are clinically useful, but none is diagnostic on its own. Some athletes with REDs have normal body mass, stable weight, or no diagnosed eating disorder, and laboratory results may appear normal early in the syndrome.

The 2023 IOC model therefore conceptualizes LEA multidimensionally, considering magnitude, duration, frequency, origin, timing, and recovery (Burke et al., 2023). This perspective distinguishes short, planned, and recovered periods of lower availability from repeated or chronic energy deficits that impair health and performance. Meal timing is also relevant: an athlete may appear to consume enough energy across 24 hours but remain under-fueled for long periods during the day because of fasted training, delayed post-exercise nutrition, or inadequate carbohydrate availability around demanding sessions.

These measurement challenges have practical implications. Researchers need comparable methods, clinicians need feasible assessment strategies, coaches need clear messages that do not turn nutrition into surveillance, and athletes need education linking fueling to adaptation, bone health, mood, immunity, recovery, and performance. Energy availability is therefore both a physiological construct and a practical communication tool for athlete-centered care.

3.3 Epidemiology and Risk Groups

The estimation of REDs prevalence is challenging because studies use a number of different populations, definitions, screening measures, and outcome measures, and there are very large differences in LEA risk. Some reports of REDs risk in track and field and endurance populations describe it as significant and higher in endurance and jumping sports than in others (Melin et al., 2019). Reviews are generally consistent in finding that REDs risk occurs in not only elite athletes, but also in recreational athletes, adolescent athletes and high level activity participants who do not refer to themselves as elite (Logue et al., 2020; Wasserfurth et al., 2020).

Some sports carry increased risk because their performance cultures reward leanness, low body mass, appearance, or weight-category compliance (Mountjoy et al., 2018; Mountjoy et al., 2023). In endurance sports such as distance running, cycling, triathlon, rowing, swimming, and cross-country skiing, athletes may perceive lower body mass as beneficial for efficiency. For aesthetic and judged sports such as gymnastics, figure skating, dancing, diving and cheerleading athletes may be subject to public judgment which exacerbates pressure over their body image. Sports such as wrestling, boxing, judo, mixed martial arts, lightweight rowing, and weightlifting are sports that fall into weight categories that require weight cutting and repeated loss of weight, whereas jumping or anti-gravity sports may emphasize a high power-to-weight ratio (Mountjoy et al., 2018; Mountjoy et al., 2023).

Although sport category alone cannot identify risk, an athlete in a team sport may develop REDs, when training volume is higher, training days involve skipped meals during travelling and suboptimal post-training refueling, or they are pressured by a coach to achieve different body composition. A marathon recreational athlete may develop REDs while doing high volume training with high job stress and caloric restrictions. A para athlete may present with altered body composition assessment, GI limitations or fuel delivery logistic issues. A male cyclist may show hormonal suppression with outwardly average body mass. These examples show why screening should be based on symptoms and risk factors rather than assumptions or stereotypes.

The adolescent population represents a critical risk group. This is because adolescents not only need to consume enough energy to train, but also to promote development, pubertal changes, and accumulation of bone mineral. Lack of energy availability during this developmental stage can affect reproductive maturation, peak bone mass accumulation and risk of stress injuries. The social environment is another critical factor that is essential to consider during this developmental stage; adolescents are susceptible to influence from coaches, parents, peers, and social media. They may have very limited say in food consumption at school, whilst travelling, or competing, and face pressure for early specialization, and the maintenance of high volume and intensity training (De Souza et al., 2014; Mountjoy et al., 2023).

Female athletes were studied more prominently because menstrual irregularity is the only obvious clinical manifestation and because the Triad model was initially formulated based on the observation of female athletes. Menstrual irregularity, oligo- and amenorrhea, late menarche, and functional hypothalamic amenorrhea still serve as critical clues. Nonetheless, normal menstruation is not proof of absence of REDs, and the use of hormonal contraception may cause withdrawal bleeding mimicking menstruation that is not based on normal ovulation. The questions asked concerning menstrual history should take into account the natural menstrual cycle history before hormonal contraceptive use, use of present medications, regularity of menses, and symptoms indicative of endocrine derangements.

Male athletes are increasingly recognized as an underreported group. Male athletes with REDs may present with low testosterone, reduced libido, fewer morning erections, fertility concerns, depressed mood, fatigue, poor training adaptation, bone stress injury, or recurrent illness. BMI is likely to not effectively identify men in whom REDs is present and highlights the necessity of questioning rather than assessing visually (Holtzman et al., 2025). The societal taboo regarding men having disordered eating or eating disorders and absence of typical questioning of libido or reproductive health functions may be some of the reasons for a later diagnosis.

In addition, athletes who have histories of eating disorders or eating problems, body dissatisfaction, perfectionism, anxiety, depression, excessive exercise, or past injury should be aware of the risks. REDs and mental health may operate bidirectionally. Dietary restriction may contribute to physiological suppression and mood disturbance. Anxiety, depression or body dissatisfaction may promote the state of being underfed. For some athletes, underfeeding might initially be accidental and may later develop into a set of stringent food rules when the athlete is complimented on weight loss by the coach, or when short term performance improvement appears associated with weight loss. This pathway illustrates how sport environments can transform accidental under-fueling into more persistent disordered behavior (Pensgaard et al., 2023).

3.4 Pathophysiology and Multisystem Clinical Consequences

In REDs, the core pathophysiological mechanism is a deficit in energy available to maintain biological functions optimally. In periods of restricted energy, priorities shift to survival and functional movement, rather than non-essential or energetically expensive functions. These include reproductive downregulation, altered thyroid hormones, modified leptin and insulin-like growth factor 1, elevated cortisol, lowered resting metabolic rate, impaired bone formation, and changes in immunity (Elliott-Sale et al., 2018; Loucks et al., 2011; Mountjoy et al., 2023).

Among the best-known consequences are reproductive outcomes. In female athletes, LEA may reduce hypothalamic GnRH pulsatility and subsequent luteinizing hormone pulsatility, which may ultimately decrease ovarian hormone production. It may clinically present with luteal phase defects, oligomenorrhea, amenorrhea, anovulation or delayed menarche. Estrogen deficiency contributes to poor bone health and may potentially affect cardiovascular and psychological function as well. Menstrual dysfunction is not "normal for an athlete" and must be considered a clinical sign of where to begin an investigation of energy availability, stress, endocrine status and bone risk (De Souza et al., 2014; Loucks et al., 2011).

Male athletes may experience reduced testosterone and altered hypothalamic-pituitary-gonadal axis functioning with LEA, the signs of which include decreased libido, fewer morning erections, lethargy, impaired recovery, low mood, and reduced muscle protein synthesis. As the signs are usually private or nonspecific and may go unrecognized without direct and discreet questioning, males may be reluctant to report the signs of reproductive dysfunction or eating concerns due to stigma and the desire to avoid seeming 'weak'; hence it should be normalized during screening of male athletes (Hackney et al., 2023; Holtzman et al., 2025).

One of the most medically significant areas of consequences from LEA is the bone and this has far-reaching effects. Bones are living tissues that depend on sufficient energy intake, sufficient protein intake, a good intake of calcium and vitamin D, appropriate endocrine support and sufficient mechanical load. Effects from LEA on the bones include a reduction in bone formation, and changes in bone turnover that result in low bone mineral density and risk of bone stress injury. Stress fractures could mean weeks out of training, with stress fractures potentially recurring until the underlying problem of energy deficiency is addressed. Particular attention needs to be given to higher risk bone stress injuries like stress fractures on the femoral neck or sacrum. In adolescent female athletes, particular concern relates to compromised peak bone mass development (De Souza et al., 2014; Mountjoy et al., 2023).

These endocrine and metabolic alterations are a consequence of the body attempting to preserve energy. A lowered resting metabolic rate, altered thyroid function, low leptin, changes in insulin-like growth factor 1 and elevated cortisol could occur. Some of these changes may be beneficial in the acute response but detrimental chronically. The athlete may describe being cold, feeling that they cannot sleep well, poor recovery or inability to adapt to training. Even if test results remain within reference ranges, values may still have changed clinically for the individual athlete. This explains why test interpretation depends strongly on symptoms and history (Elliott-Sale et al., 2018; Logue et al., 2020).

The consequences associated with the blood and immune system are important. Some relevant aspects for athletes undertaking REDs include an increased risk of anemia and iron deficiency, recurrent infections of the upper airways, increased time to healing or frequent illness. The presence of the above is not exclusive of REDs but should be investigated along with fueling strategies in a high load athlete, in cases of chronicity and recurrence. The immune system relies on energy availability; therefore chronic under-fueling might not allow adequate resources to be available to effectively fight infections and repair damaged tissues. Such consequences will have a direct implication on an athlete's availability to train and compete (Logue et al., 2020; Mountjoy et al., 2023).

Gastrointestinal symptoms may be both a consequence of REDs and a contributing factor to low energy availability. Athletes might experience symptoms of bloating, constipation, premature fullness, reflux, abdominal pain or bowel habit disturbance. These symptoms may have the potential to decrease food intake and therefore energy intake. Similarly, gastrointestinal issues might also be aggravated by restrictive diets which, although high in fiber, are often energy low. Exercise-associated gastrointestinal symptoms also commonly affect endurance athletes and may impair food intake during exercise. Management approaches often involve both practical dietary intervention and gut training along with treatment of behavioral and medical factors.

The cardiovascular effects are less routinely spoken of in common sport situations, but remain a key consideration. An ongoing state of negative energy balance can impact resting heart rate, blood pressure, lipid profile, endothelial function, and autonomic balance. Although relative bradycardia can be an appropriate adaptation to exercise training in some endurance athletes, it can also be a medical danger when related to the training status, a state of fatigue and amenorrhea, the presence of dizziness, or evidence of eating disorder. Cardiologic signs should always be interpreted in the broader clinical context, and should prompt urgent medical assessment if accompanied by the presence of syncopal episodes, chest pain, profound dizziness, or any of the signs and symptoms of an eating disorder.

Psychological symptoms are part of REDs, not a separate or incidental factor. Psychological effects that can be associated with REDs can be low mood, irritability, anxiety, difficulty concentrating, obsessive thinking about body composition/food, social withdrawal and apathy. Psychological effects can sometimes occur pre LEA but also as a direct result of long-term under-fuelling. REDs can occur simultaneously with clinical eating disorders, for which a specialist approach should be taken. The IOC mental health subgroup stated that REDs and mental health have a bidirectional relationship and should be dealt with via integrated care and not a separate nutrition vs psychological approach (Pensgaard et al., 2023).

Finally, REDs influences performance. A number of performance factors may be impaired including endurance capacity, maximal strength and explosive power, motor skills (coordination), reaction time, focus and attention, decision-making, response to training stimulus and increased absences from training (illness and injury). A recent review on LEA and REDs indicated a negative relationship between several performance variables, although results and methods remain inconsistent (Gallant et al., 2025). A strong clinical message to take home is that immediate performance improvements gained from weight loss may be hiding long-term performance losses and sustained performance is dependent on sufficient energy availability.

3.5 Clinical Presentation and Red Flags

REDs are not monolithic and initial presentations may be insidious. One athlete may come in with recurrent stress fractures; one with fatigue and poor training adaptation; another with amenorrhea; another with low testosterone; another with food and weight anxiety; and another with recurrent illness. The lack of a 'classic' symptom does not rule out REDs. Clinical suspicion should increase when multiple system features are seen and occur against a background of high training load with insufficient refueling.

Red flags for a shared history include rapid weight loss, failed attempts at dieting, restricted intake of food, low carbohydrate/fat diet, missed meals, training in a fasted state, delayed post-exercise meals, poorly planned vegetarian or vegan diet, fear of weight gain, obsessive exercise, and distress when exercise is not performed. More red flags may be: recurring injuries, stress fractures, wounds that do not heal, illnesses in quick succession, constant exhaustion, disrupted sleep patterns, low mood, increased irritability, poor motivation, a decrease in work/academic performance, and avoiding social eating situations.

In female athletes, menstrual history is important. Overt red flags include primary amenorrhea, delayed menarche, oligomenorrhea, secondary amenorrhea or irregular menstrual bleeding or the cessation of a formerly regular cycle. Clinicians should enquire about use of hormonal contraceptives as withdrawal bleed can obscure a developing problem of hypothalamic suppression. Female athletes often do not bring up menstrual issues as they think this is normal in sport, and the menstrual cycle should be addressed routinely, in a non-judgmental way.

Specific signs that should be screened for in male athletes are reduced sexual desire, reduced morning erections, impotence, low testosterone levels, questions concerning fertility, ongoing fatigue, low mood and a blunted training response. It is important these questions are asked privately and compassionately as male athletes are not as likely to link sexual or hormonal symptoms with sport nutrition and may be reluctant to report symptoms due to embarrassment. Including these questions in routine athlete health screening can improve identification.

Physical signs might involve low BMI, marked recent weight loss, low percentage body fat, cold extremities, orthostatic symptoms, bradycardia, hypotension, the appearance of lanugo-like hair (in significant restriction), evidence of dental erosion (if purging occurs), or clinical signs of dehydration. Appearance cannot be relied upon as there are athletes with REDs who are underweight, normal weight, or weight stable. An athlete may have substantial lean mass but decreased energy availability. It is therefore advisable not to use the appearance of a person as a method of screening.

Performance indicators may be particularly useful in sports contexts and have been cited as a useful guide to identify potential problems and to signal performance issues when they appear and in unusual forms, for example plateaus, decreasing fitness/endurance, strength and coordination reduction, decrease in sprint speed and volume; the ability to perform previously normal training loads and extended periods of post-exercise muscular pain; the perceived exertion is very high at even moderate workloads, and failure to attend training due to recurring illness and/or injury. Coaches often see these indicators before clinicians, but coaches have not always been equipped with the knowledge to differentiate performance drop as a health sign rather than as an issue of motivation.

Table 1 summarizes common REDs warning signs. The list should not be used as a diagnostic checklist but as a guide for structured questioning and referral.

Table 1. Common warning signs that should prompt REDs risk assessment

Domain	Examples of warning signs	Clinical implication
Nutrition and body mass	Recent weight loss; skipped meals; fasted training; rigid food rules; fear of weight gain; repeated weight cutting	Explore dietary intake, energy availability, disordered eating risk, and sport pressures
Reproductive/endocrine	Amenorrhea, oligomenorrhea, delayed menarche, low libido, reduced morning erections, low testosterone	Assess hypothalamic-pituitary-gonadal function and consider REDs risk
Bone and injury	Bone stress injury; recurrent stress fractures; low bone mineral density; slow healing	Consider imaging, DXA when indicated, and nutrition/endocrine evaluation
Performance and recovery	Unexpected performance decline; poor training response; prolonged soreness; recurrent illness; persistent fatigue	Evaluate fueling, training load, sleep, illness, and overreaching
Psychological and behavioral	Anxiety around food; body dissatisfaction; compulsive exercise; low mood; irritability; social withdrawal	Screen for disordered eating/eating disorder and refer for mental health support when needed

Note. Warning signs are nonspecific and should be interpreted in clinical context. Absence of one sign does not exclude REDs.

3.6 Screening and Diagnosis

REDs screening should occur as a proactive process and not in response to a major injury or sudden performance failure. Regular annual preparticipation evaluations, mid-season health checks, post-injury evaluations and sport nutrition consultations offer an opportunity to look for risks. Screening needs to be confidential and athletes must feel safe to report the signs and symptoms, and not fear retribution or selection out of the sport.

The LEAF-Q is perhaps the most widely used questionnaire in the screening for female athletes at risk for the Female Athlete Triad, as well as other LEA-associated conditions (Melin et al., 2014). This questionnaire covers questions on injury history, gastrointestinal distress, and menstrual status. Although this questionnaire has been utilized quite a bit, practitioners should be aware of its original validation and its limitations. The LEAF-Q was originally intended for use with female endurance athletes and dancers; in other groups it might not perform as well. The questionnaire should not be considered a general test for diagnosis of REDs nor does it test for REDs in males.

The IOC REDs Clinical Assessment Tool version 2 (IOC REDs CAT2) is the IOC's newest tool for clinical assessment and risk stratification (IOC, 2023, Stellingwerff et al., 2023) and can be used to assess athletes suspected of having Problematic LEA and group athletes into risk levels which could be used to guide participation in sport and return to sport. It takes into account both primary and secondary indicators as well as clinical judgment and context and is particularly helpful for realizing that REDs risk is not assessed based on a single sign/test but by the degree and nature of a confluence of findings.

The clinical evaluation of an athlete should always start with a comprehensive history. Important history domains to address include volume and intensity of training, change in load, competition calendar, nutrient intake and timing, food rules, gastrointestinal issues, supplement use, weight history, body composition methods, menstrual and reproductive health, injury history, history of illness, sleep patterns, psychological history, and sport-specific pressures. For adolescents, assessment should also include growth/pubertal stages, parents' perspectives and input, school schedule and accessibility of meals.

Nutritional evaluation should assess energy availability, macronutrient balance, carbohydrate availability, protein distribution, micronutrient risks, meal timing, post-exercise refueling, and eating behavior. Involvement of a sports dietitian is frequently beneficial. It is not intended to quantify caloric intake, but to identify a practical deficit or mismatch between nutrition and exercise; i.e., one athlete who eats a big dinner but under-fuels two training sessions a day; or one who eats enough protein but insufficient carbohydrates to sustain intensity; or one whose energy density decreases unwittingly due to selection of high-fiber, low-fat foods.

Laboratory testing might be warranted and must be individualized. Possible laboratory tests include complete blood count, ferritin, vitamin D, thyroid function tests, reproductive hormones, cortisol, metabolic panel, inflammation markers, and investigations driven by symptoms. Among female athletes, it is important to rule out pregnancy and other causes of menstrual dysfunction. Among male athletes, interpretation of testosterone should account for timing, illness, training stress and reference intervals. Laboratory results may inform risk but neither confirm nor exclude REDs.

Bone health assessment is appropriate if there is a history of stress fracture, chronic menstrual abnormalities or delayed menarche, recurring injury, significant weight loss, possible disordered eating, or another indicator of chronic LEA. Dual-energy X-ray absorptiometry is used to evaluate bone mineral density, however, bone mineral density should be evaluated in the context of age, sex, sport, and body size. Age-appropriate Z-scores (rather than T-scores) are appropriate in adolescents. Imaging for suspected stress fracture should be tailored based on symptoms and risk site.

When disordered eating, eating disorder, anxiety, depression, compulsive exercising, body dissatisfaction, trauma, perfectionism, or food-related distress is suspected, the administration of psychological assessment is appropriate. Eating disorder risk screening instruments can be useful but when the risk is moderate or high referral to an appropriately qualified mental health practitioner is required. Whether nutritional rehabilitation can be implemented depends upon the patient's psychological relationship with food and exercise.

An important point to consider is the differential diagnosis. Multiple conditions could be responsible for fatigue, amenorrhea, loss of libido, weight loss, bone pain, bowel disturbance, and mood disturbance. Assessment of REDs should not preclude investigation into causes such as thyroid dysfunction, coeliac disease, inflammatory bowel disease, anemia, infection, overtraining syndrome, depression, pregnancy, or polycystic ovarian syndrome. In clinical practice, there is likely overlap between REDs and these other diseases, highlighting the need for an inclusive clinical approach.

3.7 Management and Return-to-Play

REDs should be managed in a tailored, multidisciplinary and risk-based approach, and the central tenet remains achieving restoration of adequate energy availability. This can be achieved through increasing energy intake, reducing exercise energy expenditure, optimizing nutrient timing, correcting gastrointestinal barriers, modifying training, or combining these strategies. The priority is dictated by the REDs risk level and underlying cause, the athlete's desires, and any medical risk factors.

For mild deficits, nutrition and education may suffice. Athletes may need to incorporate snacks, provide more accessible carbohydrates, improve recovery meals, limit fasted sessions, provide higher-energy-density foods, and practice strategies for fueling while traveling. Concrete actions will be far more successful than numerical caloric goals. Adding a recovery drink after training, eating breakfast before morning workouts, adding carbs during long sessions, using larger portion sizes, or adding easily digestible, higher-energy-density foods are all examples.

Moderate cases require adaptation of training. Volume manipulation (reduction), decreased frequency of high-intensity training sessions, more rest days, cessation of supplemental conditioning and focus on rehabilitation are training modification strategies. Training modification should be presented as therapy rather than failure, because athletes may fear performance decline. Open communication between clinician, dietitian, coach and athlete is key.

In serious circumstances temporary restriction from training or competition may be necessary. 'Red flags' indicating more conservative management could include the following: 'significant signs and symptoms of eating disorder', 'medical instability', 'significant bradycardia or hypotension', 'syncope', 'high-risk stress bone injury', 'significant endocrine impairment', 'rapid intentional weight loss', 'refusal to adhere to treatment', or 'psychological crisis'. Return to full participation should be staged and related to clinical improvements rather than 'masking symptoms'.

Whenever possible nutrition rehabilitation should be supervised by an appropriate sports dietitian. Interventions should be targeted at: overall energy intake, availability of carbohydrate, distribution of protein throughout the day, micronutrients, hydration and meal timing. In athletes with bone risk assess and correct for calcium and vitamin D status. Iron deficiency should be treated where evident. Sometimes cooperation with medical practitioners will be needed in cases where the athlete suffers gastrointestinal problems that affect oral food intake.

It is important to involve the psychologist when disordered eating, eating disorders, anxiety, depression, compulsive exercise, or body image distress exist. Cognitive-behavioral methods, family-based methods for the adolescent, motivational interviewing, and sport-informed psychological care might be indicated. Patients should not simply be advised to change the behavior when the fear, identity, perfectionism, control, or social factors perpetuating the restriction have not been examined.

Structured risk assessment should guide return to play decisions. IOC REDs CAT2, a framework used to categorize athletes and inform return to play decisions, should be utilized (IOC, 2023; Stellingwerff et al., 2023). Generally, low-risk athletes may return to play under monitoring with education; moderate-risk athletes may return to play with modifications to their activity or sport, combined with appropriate treatment; and high-risk athletes may need restricted participation or to stop sport completely until they are medically cleared. Return should be gradual, with ongoing monitoring of symptom reporting, nutrition, menstrual or reproductive function, bone health, mental health and performance.

A common issue in management is that the athlete might feel that treatment equals the loss of their athlete identity, by increasing weight gain, reducing team selection, and being criticized by their peers. Management needs to emphasize that adequate fueling is part of elite athlete behavior rather than a reduction in commitment, and that it supports long-term endurance, recovery, and performance. However, coaches may either support or hinder this and therefore coaches need to be educated on the subject as a part of treatment, not just prevention.

3.8 Prevention and Practical Sport-System Pathway

Prevention is preferable to treating REDs after endocrine disruption, bone injury, psychological distress, or performance decline has already occurred. Effective prevention should operate at several levels: athlete education, coach behavior, parent and guardian awareness, clinical referral pathways, and organizational policy. Athletes should learn that food is not only fuel for exercise but also energy for recovery, endocrine function, immune defense, cognition, mood, growth, and long-term performance. Practical education should therefore include pre-session fueling, recovery meals, carbohydrate availability, travel nutrition, and warning signs of under-fueling.

Coaches and support staff are central to prevention because their language and selection practices shape athlete behavior. Comments equating low body weight with dedication, public weigh-ins, punitive fitness testing, and casual remarks about appearance may increase risk. Body composition assessment should be used only when clinically or performance-relevantly justified, conducted by qualified professionals, kept confidential, and interpreted alongside health indicators. Coaches should not be expected to diagnose REDs, but they should recognize warning signs such as persistent fatigue, recurrent injury, menstrual disruption, mood changes, and unexplained performance decline, and know how to refer athletes confidentially.

Parents and guardians are particularly important for adolescent athletes. They influence food availability, transport, sleep routines, medical access, and sport participation. Education for families should explain the importance of puberty, growth, peak bone mass development, and adequate energy intake. Missed periods, repeated injuries, severe food restriction, rapid weight loss, or persistent fatigue should not be normalized as part of sport, but treated as reasons for medical and nutritional assessment.

Sport organizations should create a tiered pathway. Tier one should provide universal education for athletes, coaches, parents, and support staff. Tier two should offer targeted screening for higher-risk groups, including endurance, aesthetic, weight-category, adolescent, injured, or high-load athletes. Tier three should provide full clinical assessment for athletes with red flags. The multidisciplinary team should include, when available, a physician, sports dietitian, psychologist, physiotherapist, strength and conditioning coach, and relevant specialists such as endocrinologists, gynecologists, or psychiatrists.

The first clinical encounter should be athlete-centered and confidential. Athletes may fear losing selection opportunities or being removed from competition; therefore, clinicians should explain that assessment aims to protect both health and performance and that participation decisions should be proportional to risk. A structured assessment should include recent training load, competition goals, injury history, menstrual or reproductive function, illness frequency, sleep, mood, dietary patterns, weight history, medications, supplements, and sport-specific pressures. For adolescents, growth, puberty, school schedule, parental input, and access to meals should also be considered.

Management actions should follow risk stratification. Low-risk athletes may require education, nutrition adjustments, and follow-up. Moderate-risk athletes may need a written treatment plan, training modification, laboratory testing, and more frequent monitoring. High-risk athletes may require restriction from competition, urgent medical assessment, or specialist mental health care, particularly when eating disorder symptoms, medical instability, syncope, severe bradycardia or hypotension, high-risk bone stress injury, or psychological crisis is present. IOC REDs CAT2 can support these decisions, but it should be used by clinicians who understand its purpose and limitations (IOC, 2023; Stellingwerff et al., 2023).

Prevention also requires attention to social and organizational determinants. Sport cultures can moralize food choices and body size, reward rapid weight loss, and frame discomfort as evidence of commitment. Financial barriers, travel schedules, limited access to food, social media comparison, and uncritical use of monitoring technologies may also contribute to risk. REDs prevention is therefore not only an educational task but also a governance issue: organizations should protect confidentiality, avoid body shaming, separate medical decisions from selection pressure, provide access to appropriate food and professional support, and promote role models who normalize fueling, recovery, and help-seeking.

3.9 Digital Health, Athlete Monitoring, and Ethical Considerations

Digital technologies are increasingly used in sport. Common examples include wearable devices, online training platforms, nutrition logs, menstrual-cycle trackers, and sleep-monitoring tools. These digital platforms can collate a vast array of data, but may be useful in REDs prevention if they allow the recognition of early patterns of excessive training load or inadequate recovery, irregular menstruation, disruption to sleep patterns, negative fluctuations in mood, recurrent infection and ill health, or imbalance of diet and energy input versus output. Conversely, they may cause harm if the enhanced scrutiny/surveillance causes increased weight obsession or anxiety.

The potential positive applications are obvious. Training load data may reflect increased energy demands. Wellness questionnaires may reveal fatigue, muscle soreness, poor sleep, and negative mood states. Menstrual charts may prompt an earlier recognition of cycle disturbances. Nutrition logs may highlight missed meals or insufficient carbohydrate intake and recovery periods. Devices may offer subtle data (resting heart rate, sleep, recovery) that when combined with a trained professional will prompt an earlier approach.

However, digital data do not constitute a diagnosis. Energy output measurements in wearables can be inaccurate. Intake may be underestimated by food logging or encourage obsessional behavior. Period tracking apps may confuse withdrawal bleeding with ovulatory bleeding. Recovery measurements can be distorted by stress, illness, travel, or a faulty device. A high-performance environment with every data point a target could lead to anxiety instead of safety. Digital information is most useful to prompt dialogue.

Ethical concerns arise because REDs monitoring may involve highly personal and sensitive information including menstrual status, reproductive history, food intake and weight patterns, emotional well-being and likelihood of injury. Athletes must understand what is recorded, who has access to it, how it is used, and whether reporting symptoms affects team selection. Consent must be real, not compelled by team membership. Data must be minimized, secure, and shared with only those necessary professionals who can use it to enhance the athlete's health.

Another significant ethical pitfall is the misuse of body composition and body weight information. Repeated weigh-ins, comparisons to others, or coach access to body composition reports could increase unhealthy practices. If body composition assessment is to take place, it must have a clear clinical rationale, be conducted at limited frequency, remain confidential, and be accompanied by nutrition and psychological support. Athlete numbers on a scale and skinfold calipers should never become athletes themselves. In many situations, performance indicators, markers of health and training consistency are far more indicative than body composition data.

Digital solutions may have their strongest utility in larger squads where direct supervision of all athletes is not possible. Short confidential screening systems may help identify which athletes warrant additional follow up. However, automated risk scoring needs to be explained to clinicians, and clearly validated. False positives may generate undue anxiety, whereas false negatives may delay treatment. Design must involve athlete input, with systems that prompt for explanations of context, not classification by algorithms.

From a social science perspective, technology alters the power relationship between athlete and institution. Monitoring can empower athletes to better understand their bodies, but it can also enable institutional control over athlete behavior. The outcome depends on governance, consent, interpretation, and trust. For REDs prevention we must include digital ethics - privacy, confidentiality, proportionality, clinical expertise, and non-punitive use. Ideally, digital systems should enable dialogue and early care rather than surveillance or selection pressure.

3.10 Special Populations

Adolescent athletes require particular attention because inadequate energy availability may affect growth, puberty, psychological development, and peak bone mass acquisition. Young athletes may have limited control over food access during school, travel, and competition, while early specialization and high training volume can increase energy demands. Screening and management should therefore be age-appropriate and may require coordination with parents, schools, coaches, and healthcare professionals.

Female athletes remain an important group because menstrual dysfunction and low bone mineral density can have long-term consequences. Education about normal menstrual function should be integrated into athlete healthcare rather than addressed only after problems occur. Clinicians should ask about menarche, cycle length, skipped periods, hormonal contraception, bone injury history, and nutritional status. Restoration of a spontaneous menstrual cycle can be one marker of recovery, but it should not be treated as the only indicator.

Male athletes are also at risk, but REDs may be overlooked because there is no direct equivalent of menstrual-cycle monitoring and because symptoms such as reduced libido, fewer morning erections, low testosterone, low mood, and impaired training response may not be reported unless asked about directly. Screening questions should therefore be normalized and asked privately, especially in endurance, leanness-focused, and weight-category sports (Hackney et al., 2023; Holtzman et al., 2025).

Para-athletes may face distinct assessment and fueling challenges. Energy expenditure estimation, body composition assessment, gastrointestinal function, thermoregulation, and food access during travel or competition may differ depending on impairment type. Current screening questionnaires may not be validated in para-athletes, so clinicians should adapt assessment to the athlete's physiology, sport, and lived experience.

Weight-category and aesthetic sports require specific prevention strategies because body mass, appearance, or judging norms may be embedded in the structure of competition. Rapid weight cycling, dehydration, restrictive dieting, and appearance-based comments should be addressed through policy, coach education, safer weigh-in procedures, and long-term planning. Team-sport athletes should also be screened when heavy schedules, travel, inadequate recovery meals, body composition targets, or psychological stress create risk of insufficient intake.

4. Limitations of the Current Review

This review is narrative rather than systematic. It does not include a formal database-search protocol, standardized study selection process, risk-of-bias assessment, or meta-analysis. It should therefore be interpreted as an integrative and clinically oriented synthesis rather than a quantitative estimate of effect sizes.

The REDs literature also has limitations. Many studies use surrogate indicators of low energy availability because direct measurement is difficult in field settings. Study populations, diagnostic approaches, screening instruments, and outcome measures differ substantially, and findings from female endurance or aesthetic-sport athletes cannot automatically be generalized to male athletes, adolescents, para-athletes, team-sport athletes, or recreational athletes.

Current guidance continues to evolve. The 2023 IOC consensus statement and IOC REDs CAT2 provide an important framework, but further validation is ongoing. Recommendations may change as new evidence emerges, especially regarding male athletes, adolescent populations, para-athletes, and the ethical use of digital monitoring.

5. Research Gaps and Future Directions

Further research is needed to improve diagnostic validity. No single biomarker confirms REDs, and studies continue to use different combinations of symptoms, questionnaires, laboratory markers, and performance outcomes. Future work should clarify how problematic LEA and REDs outcomes can be operationalized without losing the individualized clinical context emphasized in current IOC guidance (Ackerman et al., 2023).

Male athletes, adolescent athletes, para-athletes, team-sport athletes, and recreational athletes remain underrepresented in the literature. Prospective studies are needed to examine sex-specific and age-specific markers, the effects of REDs on growth and puberty, impairment-specific risks in para sport, and the extent to which findings from endurance and aesthetic sports can be generalized to other sporting contexts.

Digital monitoring requires stronger evidence. Wearables, wellness questionnaires, menstrual-cycle tracking, nutrition apps, and automated risk scores may support earlier identification, but they may also increase anxiety, surveillance, or disordered eating behaviors if poorly governed. Future studies should evaluate not only technical accuracy and prediction of injury or illness, but also athlete trust, consent, privacy, and unintended psychological effects.

More intervention studies are also needed. Current recommendations rely heavily on expert consensus, observational research, and clinical experience. Future research should evaluate nutrition education, coach education, policy changes, multidisciplinary care pathways, digital screening, and return-to-play programs using outcomes that include physiology, performance, injury recurrence, mental well-being, adherence, and long-term retention in sport.

6. Discussion

REDs illustrates the multidimensional nature of athlete health in contemporary sport. It cannot be reduced to individual willpower, dieting behavior, or body mass. Athletes make decisions about eating, training, recovery, and disclosure within environments shaped by coaching language, selection processes, peer comparison, sport-specific body ideals, technology, competition schedules, and access to expertise. For this reason, REDs should be interpreted through a biopsychosocial and sport-system perspective.

The main clinical implication is that REDs should be considered when health and performance problems occur alongside high training load, insufficient fueling, or restrictive eating patterns. Amenorrhea, reduced libido, repeated bone stress injuries, chronic fatigue, recurrent illness, mood changes, gastrointestinal complaints, poor recovery, and declining performance should not be dismissed as normal consequences of hard training. These signs may indicate that the athlete lacks sufficient energy availability to support both adaptation and health.

A second implication is that REDs is not exclusive to female athletes. The Female Athlete Triad remains clinically important, but the broader REDs framework is needed to identify male athletes, adolescents, para-athletes, and athletes from sports not traditionally associated with leanness. Male reproductive and endocrine symptoms should be normalized within athlete health screening, and clinicians should avoid relying on appearance or BMI as screening tools.

Diagnosis remains challenging because no single test confirms REDs. Underdiagnosis may occur when symptoms are attributed to training stress or motivation problems, whereas overdiagnosis may occur if any fatigue or dietary imperfection is labelled as REDs. The most appropriate approach is structured clinical reasoning that integrates history, risk factors, symptoms, objective measures, validated tools where available, and sport-specific context.

Digital technology offers both promise and risk. Used ethically, athlete monitoring may support early conversations about fatigue, menstrual disruption, recovery, illness, and fueling. Used coercively, it may intensify surveillance, weight stigma, anxiety, and disordered behaviors. Digital health tools should therefore be governed by privacy, informed consent, proportionality, clinical interpretation, and non-punitive use.

Finally, REDs challenges the false separation between health and performance. Persistent under-fueling impairs recovery, adaptation, consistency, and long-term sporting development. Protecting energy availability should therefore be understood not only as a welfare goal but also as a central component of sustainable performance.

7. Conclusions

Relative Energy Deficiency in Sport is a clinically meaningful syndrome associated with impaired energy availability. It may affect female and male athletes, adolescents and adults, recreational and elite competitors, and athletes across a wide range of sports. Its consequences may involve reproductive, skeletal, endocrine, metabolic, immune, gastrointestinal, cardiovascular, hematological, psychological, and performance-related domains.

Diagnosis is difficult because signs are often nonspecific and no single biomarker confirms REDs. Effective assessment requires integrated clinical interpretation, including medical history, training load, nutrition assessment, reproductive and bone health indicators, psychological screening, laboratory or imaging investigations when indicated, and structured tools such as IOC REDs CAT2.

Management should focus on restoring adequate energy availability, modifying training load, addressing medical issues, and providing psychological support when needed. Prevention must involve athletes, coaches, parents, clinicians, and sport organizations. Digital tools may support early identification, but only when integrated into confidential, athlete-centered systems that protect privacy and avoid punitive surveillance.

Future longitudinal and intervention studies are needed to refine diagnostic criteria, validate screening tools across diverse athlete groups, investigate male, adolescent, and para-athlete populations, and evaluate prevention and treatment programs. REDs should be viewed as both a clinical syndrome and a reflection of sport culture. Athlete health must be the cornerstone of sustainable performance systems.

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