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Primary, Secondary, and Tertiary Prevention of Relative Energy Deficiency in Sport (REDs). A Narrative Review by a sub-group of the IOC consensus on REDs.

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ABSTRACT

Relative Energy Deficiency in Sport (REDs) is common among female and male athletes representing various sports at different performance levels, and the underlying cause is problematic low energy availability (LEA). It is essential to prevent problematic LEA to decrease the risk of serious health and performance consequences. This narrative review addresses REDs primary, secondary, and tertiary prevention strategies and recommends best practice prevention guidelines targeting the athlete health and performance team, athlete entourage (coaches, parents, managers), and sport organizations. Primary prevention of REDs seeks to minimize exposure to and reduce behaviours associated with problematic LEA. Some of the important strategies are educational initiatives and de-emphasizing body weight and leanness, particularly in young and sub-elite athletes. Secondary prevention encourages the early identification and management of REDs signs or symptoms to facilitate early treatment to prevent development of more serious REDs outcomes. Recommended strategies for identifying athletes at risk are self-reported screening instruments, individual health interviews, and/or objective assessment of REDs markers. Tertiary prevention (clinical treatment) seeks to limit short- and long-term severe health consequences of REDs. The cornerstone of tertiary prevention is identifying the source of and treating problematic LEA. Best practice guidelines to prevent REDs and related consequences include a multi-pronged approach targeting the athlete health and performance team, the athlete entourage, and sport organizations, who all need to ensure a supportive and safe sporting environment, have sufficient REDs knowledge, and remain observant for the early signs and symptoms of REDs.

Key words: Relative, Energy, Deficiency, Athletes, Preventive medicine

INTRODUCTION

Relative Energy Deficiency in Sport (REDs) is a syndrome caused by exposure to problematic (prolonged and/or severe) low energy availability (LEA) (1). Problematic LEA and REDs are common among both female and male athletes at different ages and performance levels and may result in serious health and performance consequences (1). Hence, there is a need for prevention strategies to mitigate REDs.

Prevention of a health condition may be described in terms of primary, secondary, and tertiary prevention where primary prevention aims to prevent a disease from ever occurring, secondary prevention emphasises early disease detection, and tertiary prevention targets both the clinical and outcome stages of a disease, also commonly used synonymously with treatment (2). Transferring these definitions to the syndrome of REDs and considering that problematic LEA is the underlying etiological factor, primary prevention should prioritize modifying risk factors for problematic LEA exposure, secondary prevention should encourage early identification and management of REDs signs and symptoms, and tertiary prevention should seek to limit the longer-term health and performance consequences of the syndrome (Figure 1). To date, there are no publications detailing a broad and thorough understanding of the prevention of REDs.

The main aim of this narrative review is therefore to address REDs primary, secondary, and tertiary prevention strategies. A secondary aim is to recommend best practice guidelines targeting the athlete health and performance team, the athlete entourage, and sport organizations.

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METHODS

We conducted a narrative review aimed to provide a general overview of the existing literature on the prevention strategies related to REDs, rather than to answer a focused research question or to conduct an exhaustive literature review, as appropriate for a systematic or scoping review. The co-author subgroups working with primary, secondary, and tertiary prevention were tasked to explore relevant databases for inclusion of scientific literature related to their specific prevention area.

Equity, diversity, and inclusion statement

The author group included six women and two men representing a variety of disciplines to cover the holistic perspective of this review paper (e.g., sports medicine, endocrinology, pediatrics, internal medicine, psychology, nutrition, exercise physiology). The authors represented the following nationalities: American, Canadian, German, Israeli, Norwegian, and Swedish. Our review paper examined the topic of REDs prevention in a broad perspective in terms of gender, race, age, demographics, sport disciplines, and socioeconomic status.

PRIMARY PREVENTION

Background

Primary prevention aims to prevent a disease prior to its occurrence by minimizing exposure to hazards and increasing resistance in case of exposure (Figure 1) (2). Target groups for primary prevention of REDs should include the athlete health and performance team (e.g., physicians, physiotherapists, dietitians, psychologists, and physiologists), athlete entourage (e.g., coaches, parents, and managers), and sport organizations. Specific at-risk groups, including athletes in weight-sensitive and leanness-demanding sports, and female and adolescent athletes, warrant particular focus (3). As problematic LEA is the underlying cause of REDs, the objectives of primary prevention are to minimize exposure to and reduce behaviours associated with LEA (Table 1).

1. *Exposure to LEA.* LEA can result from intentional dietary restriction to reduce body weight or achieve leanness (4, 5). LEA can also occur inadvertently from poor nutritional knowledge, lack of time, food insecurity, low energy density diets, or exercise-related changes in appetite (4, 6, 7). Given that LEA is a mismatch between dietary energy intake and exercise energy expenditure, increases in training volume or intensity may also contribute to LEA.

2. *Behaviours associated with LEA.* Restrictive eating is often associated with concerns around body weight and shape, which occur frequently in weight-sensitive and leanness-demanding sports (8). Weight and shape concerns can be exacerbated from within and outside the athletic community. Although assessment and management of body weight and composition are often considered important for optimizing athletic performance (9), focus from coaches on athletes' body composition and weight often cause concerns (10, 11), especially for young athletes who are at increased risk of developing negative physical and mental health outcomes (1, 5). Peers (teammates, competitors) can also be sources for unhealthy dieting behaviours (10) since influential athletes may intentionally or unintentionally put pressure on others (5). Social media exposes athletes to potential behaviours in a variety of ways, including issues related to body image, body shaming, and bullying (12, 13). Independent of the source, negative comments and weight pressure can reinforce body dissatisfaction and restrictive eating

behaviour (8, 11, 12). Recent literature suggests that exercise addiction may present an additional risk factor for REDs (14, 15).

3. *Non-modifiable risk factors for LEA.* Although any athlete can develop REDs, the risk is highest in weight-sensitive and leanness-demanding sports, including but not limited to weight class sports (e.g., combat disciplines), aesthetically judged sports (e.g., gymnastics), sports in which a low body weight might provide a performance advantage (e.g., anti-gravity disciplines, such as high jump), and in sports with high exercise energy expenditure (e.g., endurance disciplines) (9). Due to the prominence of menstrual disturbances as a symptom of exposure to problematic LEA and the greater prevalence of risk behaviours associated with REDs [e.g., disordered eating (DE) behaviour], female athletes have historically been, and still are considered at high risk of problematic LEA and associated symptoms (1, 16)]. While other non-modifiable risks such as genetic factors may exist, there is currently insufficient scientific evidence to support genetic factors contributing to REDs (17).

Primary prevention strategies

The central roles of unhealthy dietary and/or exercise behaviours in the development of problematic LEA and REDs necessitate that primary prevention strategies focus on education about the importance of adequate energy availability to ensure optimal health and performance (1, 3, 18). Educational initiatives targeting all individuals in the athlete's ecosystem (the athlete health and performance team and members of the entourage) should include strengthening of protective factors and reducing risk factors (see Table 1) (1, 3, 9, 19).

Table 1. *Risk factors and approaches for primary prevention of REDs in healthy athletes.*

Risk Factors	**Primary Prevention Recommendations**
Intentional exposure to LEA	
Intentional reduction in body weight or body fat	• Implement in elite athletes only • Obtain athlete consent and only share results with athlete approval • Careful planning (e.g., consider the athlete's season) and follow-up (e.g., communication strategy, close compliance monitoring, and adequate recovery) by the multidisciplinary health and performance team • Ensure athlete physical and psychological readiness (e.g., pre-screening of disordered eating behaviour) • Utilise evidence-based rationale and set realistic goals for body weight and body composition • Employ appropriate weight and body composition methods used by licensed personnel who are trained in the specific methods • Maintain energy deficits in moderation • No assessment of body weight and composition unless for medical purposes for athletes < 18 years old
Inadvertent exposure to LEA	
Lack of knowledge	• Educate about the importance of adequate energy availability to ensure optimal health and performance • Teach adequate fuelling strategies for various training durations and intensities as well as growth
Behaviours associated with LEA (e.g., restrictive diet, compulsive exercise)	• Strengthen protective factors (e.g., self-esteem and inspirations, positive body image, acceptance of physical changes related to adolescence, media literacy, balanced nutrition, and training) • Reduce risk factors (e.g., internalization of an 'ideal body type', body dissatisfaction, peer pressure, fat shaming) • Involve teammates and the athlete entourage (e.g., coaches)
Non-modifiable risk factors	• Advocate for/implement sport rule and regulation changes to minimise emphasis on body weight (e.g., weight categories, timing of weigh-ins, course profiles) and appearance (e.g., sport uniforms)

Studies on the prevention of eating disorders (EDs) among adolescent and collegiate athletes suggest that interactive workshops involving discussions or cognitive dissonance tasks can promote a positive body image, encourage self-care, and reduce ED risk factors (19-21). Similar findings have been reported in female dancers (22), and in female and male collegiate athletes (20, 23, 24). Considering these promising findings in light of the established links between body dissatisfaction, DE behaviour/EDs, and LEA (25), a similar approach may be effective in preventing problematic LEA and REDs.

Prevention strategies should be appropriate for age, gender, competition level, and sport discipline, and account for socio-cultural aspects of the target audience (26). A critical period for primary prevention is the transitional time of puberty. Communication with this age group should focus on themes related to variations in body shape, natural biological and psychological changes, maturation, and how these factors relate to athletic performance, positive behaviours, peer pressure resistance, and building an environment that supports a positive body image (19). To minimize the risk of developing REDs, athletes and their health and performance team should aim to de-emphasize body weight and leanness, particularly in young and sub-elite athletes (9). Except for medical purposes (e.g., growth progression), assessment of body weight and composition are not recommended for underage athletes (1, 8, 27). When weight loss or reduction in body fat are recommended for elite athletes, careful planning and realistic body weight/composition goals are essential, and necessary energy deficits should be kept in moderation to avoid problematic LEA (Table 1). Ideally, the elite athletes and their health and performance team initiate an evidence-based management and rationale for weight or body fat reductions (Table 1) (1, 5). Sport organizations should be aware of the implications of rules related to body weight (e.g., weight-category sports) and sport uniforms (e.g., female beach volleyball), and course designs that include more climbing and thereby favor lighter athletes (e.g., cross country skiing, road cycling) that might create a culture of dieting and unhealthy eating practices (Table 1).

There is little evidence of REDs primary prevention programs’ efficacy in healthy athletes. Although education interventions may improve knowledge (1, 28, 29), it remains unclear if they result in behaviour changes that reduce the risk of developing REDs (18).

SECONDARY PREVENTION

Secondary prevention encourages the early identification and management of REDs signs or symptoms to facilitate early treatment, thus preventing the development of more serious REDs outcomes (e.g., osteoporosis, EDs) (Figure 1). Self-reported screening instruments, individual health interviews, and objective assessment of REDs markers may be useful strategies for secondary prevention.

Subjective assessment of symptoms

Screening of self-reported symptoms either by questionnaires or individual health interviews are convenient and simple methods for the early identification of REDs. Relevant *physical symptoms* include menstrual dysfunction in females (30-32), reduced erectile function in males (33), recurrent illnesses (34), and injuries (31, 35). *Psychological symptoms* may include mood changes, reduced well-being, and depression (1, 36). Symptoms can also be related to an athlete's *behaviour*, such as excessive exercise, frequent non-performance-related measurements of body weight or composition, or DE behaviour/EDs (1). To date, no validated screening instrument includes all of these aspects. Hence, a combination of instruments should be used to increase the possibility of optimal secondary prevention of REDs.

Validated or tested questionnaires used in athletic populations to assess LEA, REDs, and DE behaviour are summarized in Table 2. For a more complete list of questionnaires frequently used in athletic populations, also including non-validated/tested questionnaires (37-43), see Supplemental Table 1.

The Low Energy Availability in Females Questionnaire (LEAF-Q) was originally validated against clinical signs of LEA [e.g., functional hypothalamic amenorrhea (FHA) assessed by gynaecological examination, low bone mineral density (BMD) assessed by dual energy X-ray absorptiometry (DXA), and blood biomarkers] in female endurance athletes (31) and is also commonly used for assessing physiological symptoms of LEA in other female athletic groups (44). To date, only one questionnaire has been developed and tested for use in male athletes [the Low Energy Availability in Males Questionnaire (LEAM-Q)] (45). Validation of the LEAM-Q was based on clinical verification of signs of LEA (e.g., blood biomarkers and low BMD) in elite and sub-elite male athletes from multiple countries and ethnicities, including athletes from a variety of endurance and weight-sensitive sports. While several questionnaire variables had sufficient sensitivity, only low sex drive score was associated with perturbations in key clinical REDs signs (e.g., low blood testosterone concentrations) (45).

It is recommended that questionnaires identifying symptoms of EDs should be included in REDs screening (1). The Eating Disorder Examination Questionnaire (EDE-Q) (46) is frequently used to assess behavioural and cognitive symptoms of EDs. Other DE/EDs screening instruments used in athletic populations are shown in Table 2. Furthermore, exercise addiction has been shown to be related to REDs in both male and female athletes (14, 15, 47). Consequently, validated questionnaires about excessive training behaviour may prove useful in a REDs assessment, although none have been validated yet for this purpose (Table 2). There is some evidence that other psychological symptoms, such as mood disturbances/fluctuations, cognitive dietary restraint, perfectionistic tendencies, sleep disturbances, depressive symptoms, anxiety, and reduced well-being, are associated with REDs (1, 36). Therefore, screening for psychological and behavioural symptoms should also be considered in future research and clinical practice.

Most questionnaires have been developed and validated for an adult athletic population; adolescent athletes, however, are at high risk for REDs and stand to benefit substantially from secondary prevention. Of note, the Brief Eating Disorder in Athletes Questionnaire (BEDA-Q) (48), the REDs Screening Tool (RST) (49), and the Disordered Eating Screen for Athletes (DESA-6) (50) show promising results for screening adolescent athletes (Table 2). To date, no validated screening questionnaire for REDs in para athletes has been published.

Table 2: *Questionnaires validated/tested in athletic populations to assess LEA, REDs, and DE behaviour.*

Questionnaire	Validated in population	Main findings
LEAM-Q, 33 items (45)	Elite and sub elite male athletes representing a variety of endurance and weight-sensitive sports	Validated against clinically verified REDs conditions and biomarkers. Sufficient sensitivity of dizziness, illness, fatigue, and sex drive scores. Only low sex drive could distinguish between LEA cases and controls
LEAF-Q, 25 items (31)	Elite female endurance athletes	Validated against clinically verified REDs conditions and biomarkers. Sufficient sensitivity (78%) and specificity (90%) to identify LEA, FHA and/or low BMD
(44)	Elite and pre-elite female athletes in a mixed-sport cohort	Validated against clinically verified REDs conditions and biomarkers. Sufficient sensitivity to identify low BMD (100%) and FHA (80%)
RST, 7 components (49)	Middle and high school female and male athletes	Tested against the PPGE, with a positive correlation between RST and PPGE (female version). The male version has not been tested
DESA-6, 6 items (50)	Adolescent female and male high school athletes	Validated against clinical interview. Sufficient sensitivity (92%) and specificity (86%) to identify DE
BEDA-Q, 9 items (48)	Adolescent female elite athletes	Validated against EDI-2 and clinical interview. Sufficient sensitivity (82%) and specificity (85%) to identify EDs
PST, 18 items (51)	Female collegiate athletes	Validated against clinical interview. Sufficient sensitivity (87%) and specificity (78%) to identify EDs
FAST, 33 items (52)	Female athletes	Tested against EDE-Q, EDI-2, and BTR with positive correlations between FAST and EDE-Q and EDI-2

SCOFF, 5 items (53)	Females	Tested against EDI and BIT in EDs patients and controls. Sufficient sensitivity (100%) and specificity (88%) to identify DE/EDs
(54)]	Female and male national level athletes	Validated against clinical interview. Sufficient sensitivity (94%) and specificity (88%) to identify EDs
AMDQ, 119 items (55)	Female college athletes	Validated against EDI-2, BTR and clinical interview. Sufficient sensitivity (80%) and specificity (77%) to identify DE/EDs
EDE-Q, 28 items (56)	Female general population and female EDs patients	Validated against clinical interview. Close agreement between EDE-Q and the interview concerning frequency of purging and dietary restraint severity
(54)	Female and male national team level athletes	Validated against clinical interview. Sufficient sensitivity (90%) and specificity (100%) to identify DE/EDs
EAI, 6 items (57)	Females and males mixed exerciser sample	Tested against EDS and OEQ. Positive correlations between EAI, EDS and OEQ
(58)	Female and male athletes	Tested against 3 questions supposedly reflecting EA. Positive correlation between EAI and all questions

Abbreviations*:* *AMDQ*=Athletic Milieu Direct Questionnaire; *BEDA-Q*=Brief Eating Disorder in Athletes Questionnaire; *BMD*=Bone Mineral Density*; DE*=Disordered Eating*; BIT*= Bulimic Investigatory Test; *BTR*= Bulimia Test-Revised; *DESA-6*=The Disordered Eating Screen for Athletes; *EA*=Exercise Addiction; *EAI*=Exercise Addiction Inventory; *EDE-Q*= Eating Disorder Examination Questionnaire; *EDs*=Eating Disorders; *FAST*= The Female Athlete Screening Tool; *GI*=Gastrointestinal; *LEAF-Q*= Low Energy Availability in Female Questionnaire; *LEAM-Q*=Low Energy Availability in Males Questionnaire; *MD*=Menstrual Dysfunction*; OEQ*=Obligatory Exercise Questionnaire; *PPGE*=Pre-Participation Gynaecological Examination; *PST*=The Physiologic Screening Test; *RST*=RED-S Specific Screening Tool; *SCOFF*=Sick, Control, One stone, Fat and Food questionnaire.

While questionnaires are easy to use, response bias and under-reporting may occur. Thus, to allow a more in-depth athlete clinical assessment, questionnaires should be accompanied by other information-gathering tools, such as personal interviews (59). Observation from coaches, parents, health personnel or others may serve as an opportunity to identify symptoms, such as excessive exercise behaviour, expressed need for recurrent and non-performance-related measures of body weight and composition, or concerning eating or dieting related behaviours.

Objective assessment of symptoms

Objective assessment of REDs signs may be used for the early identification of REDs and verification of self-reported symptoms (Table 3). For example, self-reported menstrual dysfunction is strongly associated with clinically verified FHA in female endurance athletes (31). Furthermore, FHA is associated with lower female sex hormones and lower BMD (60). In males, sub-clinically or clinically low testosterone levels are potential biomarkers of problematic LEA (61, 62) and are associated with low libido (45) and bone stress injuries (63).

Evaluation of multiple REDs signs is necessary to accurately diagnose and determine the severity of REDs (Table 3) (1). For example, although FHA is commonly reported among female athletes (64), polycystic ovary syndrome (PCOS) is one of the most frequent menstrual disturbances in the general population, and athletes with PCOS may concomitantly have problematic LEA with FHA (65), EDs, or low BMD (31). Therefore, FHA is a diagnosis of exclusion (Table 3). Studies in recreationally active women have reported a 12–30% prevalence of asymptomatic anovulation (64). It is recommended to confirm ovulation over at least 3 consecutive menstrual cycles to verify eumenorrhea in female athletes (66).

It is important to note than many female athletes use contraceptives containing exogenous hormones (67) and may or may not have a withdrawal bleed, which is not equivalent to a menstrual cycle. Hence, assessing normal reproductive function can only be performed in the absence of exogenous hormones.

There are strong associations between signs of problematic LEA (e.g., low oestrogen/testosterone levels) and adverse bone parameters (1, 63). Bone health can be assessed by DXA in the setting of suspected problematic LEA or recurrent bone stress injuries. Because of the osteogenic stimulus of weight-bearing exercise, low BMD in athletes has been defined as a Z-score < -1.0, as opposed to < -2.0 in the general population (16), and warrants further clinical evaluation. However, it has recently been proposed that there is a need for sport discipline-specific Z-score ranges in order not to underestimate low BMD in athletes representing high impact sports (68).

Sub-clinically or clinically low serum concentration of total or free triiodothyronine (T3) is a valid LEA biomarker in both male and female athletes (31, 61, 63).

Many athletes with REDs have a body weight within the normal reference range and may be lean or have more body fat than expected (69), and athletes with EDs may have a body weight that is under, within or above the normal reference range (70). Thus, it is important to assess athletes for REDs independent of percent body fat, body weight and body mass index.

Secondary prevention is embodied in step one and two of the IOC REDs Clinical Assessment Tool 2 (REDs CAT2), which is a three-step approach framework to operationalise the secondary and tertiary prevention of REDs (1). When early signs or symptoms of REDs are identified, it is necessary to progress to tertiary prevention corresponding to step three of the REDs CAT2, with focus on clinical diagnosis and treatment to safeguard athletes’ health.

TERTIARY PREVENTION

General principles

The objective of tertiary prevention (clinical treatment) is to promote rehabilitation to prevent or limit short- and long-term severe health consequences of REDs (Figure 1). Accurate diagnosis of REDs vs. other causes of the clinical presentation is essential for determining correct treatment and subsequent commencement of an effective management program. The cornerstone of treatment is to identify the source of and treat the underlying cause: problematic LEA. Reversing LEA can be achieved by increasing energy intake, decreasing exercise energy expenditure, or a combination of both. A multidisciplinary clinical team is recommended for comprehensive treatment. This team can include clinicians specializing in sports medicine, sports nutrition, sports psychiatry, sports psychology, exercise physiology, endocrinology, and gynaecology (3). The expected timeline for recovery from REDs is variable and depends on multiple factors, such as the specific REDs condition, the severity, the presence of other medical issues, and the underlying cause of LEA (71-74). The following section outlines treatment principles for the possible clinical sequelae of REDs (Table 3).

Table 3: *Recommended treatment of outcomes of Relative Energy Deficiency in Sport (REDs).*

Body system dysfunction	**Examples of clinical presentations**	**Examples of differential diagnoses**	**Examples of treatment recommendations in addition to increasing energy availability**
Impaired reproductive function among females	Primary/secondary amenorrhea/oligomenorrhea; Anovulation; Short luteal phase	Pregnancy; Use of hormonal contraceptives; Polycystic ovary syndrome; Pituitary mass (e.g., prolactinoma)	Avoid use of combined oral contraceptive pills to induce monthly bleeding
Impaired reproductive function among males	Reduced libido and/or erectile function	Medication/drug side effects; Mental disorders (e.g., depression); Primary hypogonadism	Avoid use of exogenous hormone administration
Impaired bone health	Recurrent and/or high-risk BSI (e.g., femoral neck); Fragility fracture; Low BMD	Malabsorption syndromes Other metabolic bone diseases; Medication/drug side effects; Low sex hormones from other causes	Ensure sufficient calcium and vitamin D intake and correct vitamin D level if low Adolescents and women without menstrual resumption after a reasonable trial of EA improvement: consider transdermal 17-β-oestradiol with cyclic oral progesterone
Impaired gastrointestinal function	Bloating; Diarrhoea; Subjective fullness; Constipation	Irritable bowel syndrome; Inflammatory bowel disease; Celiac disease; Food intolerances	Cognitive behavioural therapy for functional gastrointestinal disorders; Medications can be used to improve specific symptoms on an interim basis, such as: Metoclopramide for gastroparesis; Ondansetron for nausea; and Sufficient fluid intake and/or polyethylene glycol for constipation
Other endocrine system impairments		Pituitary mass (e.g., prolactinoma); Primary hypothyroidism; Overtraining syndrome; Fatigue; Hair loss	Consider referral to endocrinologist for assessment and monitoring Avoid hormonal replacement for transient hormonal dysfunction of REDs, such as decreased T3 Impairments should improve with EA improvement

Iron deficiency	Fatigue, compromised physical and cognitive function	Other diet- or exercise related causes (e.g., low iron intake or bioavailability) Menorrhagia; Metrorrhagia; Menometrorrhagia	Iron supplementation to ensure ferritin level above 30 mcg/l
Urinary incontinence	Stress and urge urinary incontinence	Pelvic floor trauma (e.g., childbirth, surgery); Radiation; Nerve/muscle damage from traumatic injury; Urinary tract infection	Pelvic floor muscle training; Lifestyle modification; Pessaries; Surgery
Mental health symptoms and disorders	EDs/DE behaviours Depressed mood Anxiety Sleep disturbances	Substance misuse; General medical conditions; Post-traumatic stress disorder; Obsessive compulsive disorder Primary underlying mood disorder Primary underlying anxiety disorder Apnoea; Drug side effects	Specialized ED/DE inpatient or outpatient clinic treatment therapy Adjuvant pharmacotherapy as clinically indicated (e.g., SSRI) Adjuvant pharmacotherapy as clinically indicated (e.g., anxiolytics) Sleep hygiene education; Cognitive behavioural therapy
Cardiovascular complications	Hypotension; Orthostatic hypotension; Bradycardia; Endothelial dysfunction; Unfavourable lipid profiles	For endurance athletes, 40-60 beats/min can be a normal training adaptation; Drug side effects (e.g., beta blockers); Familial hypercholesterolemia; Structural heart disease; Conduction disease	Severe bradycardia with orthostatic hypotension can be life-threatening; consider training restrictions until HR and orthostatic BP are corrected
Attenuated growth and development	Stunted growth and delayed non-constitutional pubertal development	Primary GH or IGF-1 deficiency; Pituitary disorders	Monitor growth over time Consider referral to endocrinologist if not improving with EA improvement
Compromised immune system	Increased illness susceptibility mostly URTI symptoms	Low CHO and/or micronutrient intake; Malignancy, Other chronic conditions; Poor sleep; Stress	Sufficient CHO and/or micronutrient intake

Abbreviations: *BP*=Blood Pressure; *BSI*=Bone Stress Injury; *CHO*=Carbohydrates; *DE*=Disordered Eating Behaviour; *EA*= Energy Availability; *ED*=Eating Disorder; *DSM-5-TR*=Diagnostic and Statistical Manual of mental disorders (5th edition) text revision; *GH*=Growth Hormone; *GI*=Gastrointestinal; *HR*=Heart Rate; *IGF-1*=Insulin-like Growth Factor-1; *SSRI*=Selective Serotonin Reuptake Inhibitor; *T3*=Triiodothyronine; *URTI*=Upper Respiratory Tract Infection.

Impaired reproductive function

Correcting LEA is the mainstay of treatment for hypothalamic–pituitary–gonadal (HPG) axis dysfunction in both sexes (1, 60), but few intervention studies have been performed (72, 73, 75). There is limited evidence in women with FHA that cognitive behavioural therapy lowers circulating cortisol levels and improves reproductive function (76).

Impaired bone health

Both the timing and duration of LEA are particularly relevant when considering bone-related REDs outcomes (e.g., bone stress injuries, low BMD). Adolescence is a critical time of peak bone mineral accrual for both females and males, with peak bone mass typically achieved around the end of the third decade and most bone accrual having occurred by age 20 years (77). Development of REDs in childhood or adolescence necessitates swift treatment to prevent long-term consequences. With nutritional and menstrual recovery in REDs, some "catch-up" bone accrual may occur, but less so if problematic LEA continues into young adulthood and beyond with increased risk for bone stress injuries, premature osteoporosis, and full fractures over time (78).

Recommendations regarding optimal calcium and vitamin D intake vary depending on national recommendations; correcting LEA and optimizing these bone-building nutrients is important (Table 3).

In adolescent and young adult female athletes with FHA, 12 months of transdermal 17-β oestradiol with cyclic oral progesterone improved DXA-measured BMD and was superior to oral contraceptives and no hormonal treatment (79). Thus, in female adolescents and adults, this treatment may be an appropriate adjunct to nutritional intervention (60).

The negative bone consequences of LEA are less studied in male athletes than female athletes, though it has been shown that low BMD and bone stress injuries occur in LEA-exposed exercising men (63, 80). As with female athletes, correcting LEA is the mainstay of treatment, but adjunctive treatment with exogenous male reproductive hormones in male athletes has not been studied and is not recommended. While oestrogen is an important hormone for bone development for males, exogenous oestrogen treatment would lead to potentially unwanted feminizing effects (81).

Impaired gastrointestinal function

Cross-sectional studies have demonstrated higher prevalence of gastrointestinal (GI) issues in female athletes with LEA compared to those with adequate energy availability (31, 47), and in male athletes with DE behaviours compared to controls (47). The treatment of GI consequences of REDs is derived from studies of patients with EDs, where GI complications are thought to stem from a) poorly managed medical conditions that have GI-predominant symptoms (e.g., celiac disease); b) physiological and anatomical changes that result from EDs and malnutrition; and c) functional GI diseases that frequently accompany malnutrition (e.g., motility disturbances, visceral hypersensitivity, mucosal changes, altered gut microbiome) (82).

As athletes attempt to increase energy availability, it is important to determine the cause of various GI complaints, such as clarifying if abdominal pain or diarrhoea are from an underlying condition (e.g., celiac disease, inflammatory bowel disease). Consultation with a physician and/or a registered dietitian can aid in narrowing the differential diagnosis or when GI-specific adjunctive treatment is needed. Medications can be used to improve specific symptoms (e.g., constipation, diarrhoea, bloating) on an interim basis until symptoms improve with improvement in EA.

Other endocrine system impairments

Various endocrine systems are interconnected and disrupted with LEA (83). Most hormonal disruptions seen in REDs [e.g., decreased T3 and insulin-like growth factor 1 (IGF-1), increased cortisol] are the result of problematic LEA exposure, and resolution of LEA typically improves the hormonal disruptions (1).

Iron deficiency

LEA may increase the risk of iron deficiency due to a lower dietary iron intake and/or a lower iron bioavailability (84). Dietary factors (e.g., vegan diet) may reduce iron absorption (84), as well as elevated hepatic hepcidin levels post-training (85). LEA may increase the hepcidin concentration directly or indirectly via low carbohydrate availability, low oestrogen or testosterone levels, and/or interleukin (IL)-6 induced alterations in hepcidin levels post-exercise, and thereby increase the risk of iron deficiency (85). Consequently, iron intake to ensure a ferritin level above 30 mcg/l, in addition to general nutritional rehabilitation to improve LEA, is appropriate (86). Consuming a diet high in iron is often not enough to replete iron stores in an athlete with iron deficiency, and 100 to 200 mg of elementary iron intake every other day until ferritin normalises is recommended (84). Iron supplementation alone, however, is not a panacea for an athlete's iron deficiency, and diagnosing and treating the underlying cause is paramount (85).

Growth and development

In young athletes with stunted growth and delayed non-constitutional pubertal development due to REDs, the treatment is restoring energy availability and body weight (74, 87). Growth hormone (GH) and IGF-1 therapy have been studied in non-athletes with anorexia nervosa, but currently are indicated only if there is a primary GH deficiency or other endocrinopathy (1, 88).

Mental health

Treatment of mental health symptoms related to REDs may occur in outpatient or inpatient settings depending on the severity. Psychotherapy is an integral component to the treatment of DE behaviour/EDs and can occur simultaneously with or subsequent to nutritional rehabilitation; the order of treatment is determined on a case-by-case basis. Weight-restoration with repletion of energy availability has been shown to improve cognitive function and mood in anorexia nervosa (89). Additionally, treatment of other underlying psychologic illnesses (e.g., depression, anxiety, sleep disorders) should be prioritized in the overall treatment scheme. Pharmacotherapy is typically recommended for treating comorbid psychiatric illnesses, not primary treatment of DE behaviour/EDs. Bupropion is contraindicated in anorexia nervosa and bulimia nervosa treatment because of an association with higher seizure incidence (90). Patients with anorexia nervosa have an increased risk of suicide (91). Therefore, REDs and sports-related presentations of DE behaviour/EDs must include a suicide risk assessment.

Other potential mental health outcomes of REDs include depression, anxiety, and sleep disturbances (36). As an adjunct to correcting the underlying LEA and psychotherapy, relevant pharmacotherapies should be implemented with consideration of the potential negative impacts on sport performance, safety risks, and limitations imposed by the World Anti-Doping Agency (WADA) Prohibited List. Sleep hygiene education and cognitive behavioural therapy have been helpful in treating sleep disturbances in the athlete population (92).

Cardiovascular

Cardiovascular complications of severe LEA have been well-described in patients with anorexia nervosa (93). Bradycardia can be a normal training adaptation (94). However, bradycardia and orthostatic hypotension are seen in severe LEA states (e.g., anorexia nervosa) and can be life-threatening (93). Thus, bradycardia and orthostatic hypotension should be considered in the context of suspected problematic LEA and may require a higher level of care and abrupt cessation of training (95).

Endothelial dysfunction and unfavourable lipid profiles [high total cholesterol and low-density lipoprotein (LDL)-cholesterol] have been reported in athletes with FHA (96). Improved energy availability with resumption of menses may reduce cholesterol levels and improve vascular endothelial function (97). Endothelial dysfunction, however, has not been demonstrated in males.

Immune system

Impaired immune function, primarily demonstrated as increased viral illness susceptibility (e.g., upper respiratory tract infections), is a potential presentation of REDs (34, 98). The link between LEA and immunity in athletes is complex, and many factors may mediate this relationship (98)]. Recent data suggest that low carbohydrate availability may play a significant role in negatively affecting the immune system (99). Therefore, the best treatment to offset the impaired immune function would be restoring energy and carbohydrate availability (99, 100), and may also include supplementation of probiotics, vitamin C and vitamin D (100).

Urinary incontinence (female athletes)

In a cross-sectional study of 1000 female athletes, those with indicators of LEA reported more urinary incontinence (UI) than those without LEA indicators (101). It is important to confirm the aetiology of UI by ruling out causes other than problematic LEA (Table 3). UI can be classified as stress, urge, overflow, or mixed based on the underlying cause, with stress and urge incontinence more common in female athletes with EDs than those without (102-104). As with all REDs health outcomes, attention to reversing the LEA is paramount. The most recommended treatment for UI is pelvic floor muscle training (with or without biofeedback); other treatments include lifestyle interventions, electrical stimulation, or surgery (105).

RECOMMENDED GUIDELINES FOR REDs PREVENTION

The best approach to preserve health and improve performance is primary prevention of REDs. A multi-pronged approach is recommended, targeting the athlete health and performance team, athlete entourage, and sport organizations, which together need to create a supportive and safe sport environment, have sufficient REDs knowledge, and be observant for the early signs and symptoms of REDs (Table 4).

Early identification of athletes at risk is critical to prevent the progression of REDs. Before screening for REDs, it is important to have a multidisciplinary athlete health and performance team available to identify and respond to signs and symptoms of REDs. Screening for REDs by a sports medicine physician should be included in the periodic health evaluation or by clinical indication (Table 4). The treatment strategy recommended by the athlete health and performance team should be supported by the sports organization and coaching staff to optimise athlete compliance and treatment outcomes (Table 4).

Table 4: *Suggested guidelines for prevention of REDs, targeting the athlete health and performance team, athlete entourage, and sport organizations.*

Prevention	**Athlete health and performance team**	**Athlete entourage**	**Sport organizations**
PRIMARY	Identify a rationale for altering body composition in adult elite athletes, and ensure appropriate measurement and follow-up strategies performed only by qualified/certified practitioners Provide education for athletes and coaches	Decrease focus on body weight/composition Increase REDs knowledge (e.g., early signs and how to respond to athletes with symptoms) Provide psychologically safe training environments	Develop and support a healthy sport environment around eating, fuelling, body image, and body composition Implement rule changes to decrease emphasis on body shape/weight and body composition on performance outcomes Implement sport-specific REDs-related educational programs
SECONDARY	Implement regular and evidence-based screening Conduct clinical assessments of signs of REDs (e.g., blood biomarkers, blood pressure, bone mineral density)	Be observant of early physical, psychological, and/or behavioural symptoms	Provide financial and organisational support for the early identification of REDs

		Refer athletes with symptoms to the athlete health and performance team for assessment Be supportive of the athlete and the athletes’ health and performance team	
TERTIARY	Ensure accurate diagnosis Collaborate in a multidisciplinary team Reverse problematic LEA Implement adjuvant pharmacotherapies or psychotherapies as needed Implement a graduated return to play program adjusting for energy requirements as needed	Be supportive of the athlete and the treatment regimen	Provide financial and organisational support for the treatment and return to play for athletes with REDs

CONCLUSION

The current review highlights that primary, secondary, and tertiary prevention strategies of problematic LEA and REDs are necessary to promote and protect athlete health and performance. Firstly, primary prevention is crucial to minimize exposure to and reduce behaviours associated with problematic LEA. A special focus on at-risk groups is recommended. Secondly, early identification of athletes with symptoms or signs of problematic LEA is important to prevent the progression of REDs. Recommended secondary prevention tools are questionnaires, health interviews, and objective REDs markers. Finally, tertiary prevention strategies include clinical treatment to prevent or limit short- and long-term severe health consequences of REDs. Reversing the underlying cause of REDs, namely problematic LEA, can be achieved by increasing energy intake, decreasing exercise energy expenditure, or a combination of both. A multidisciplinary approach that targets the athlete health and performance team, coaches, and sport organizations, focussing on a supportive and safe sporting environment, is recommended for the prevention of REDs.

SUMMARY BOX

What is already known?

- Male and female athletes in various sports may be at risk for developing REDs.
- Questionnaires are frequently used to identify athletes at risk of LEA and/or REDs.
- Reversal of problematic LEA is the cornerstone of treatment of REDs.

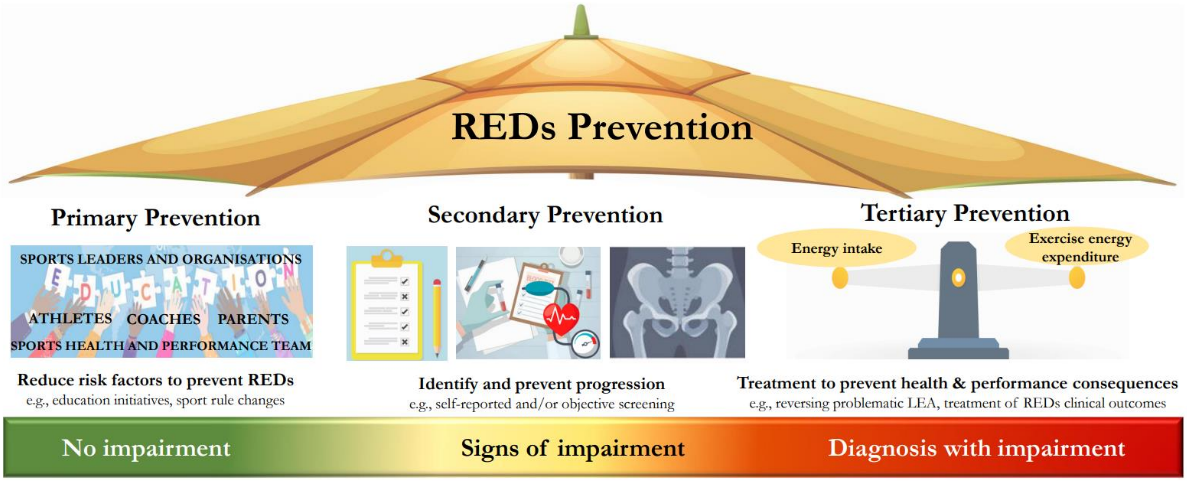
What are the new findings?

- Special consideration should be aimed towards young female athletes during the adolescent transition period that is considered high risk for problematic LEA/REDs.
- Few questionnaires used to identify athletes at risk of LEA and/or REDs are validated.

- Evaluation of multiple REDs signs and symptoms, of both physiological, psychological, and behavioural origin, is necessary for optimal identification and management of REDs.
- The REDs CAT2 provides a clinical framework to operationalise the secondary (early identification) and tertiary (treatment) prevention of REDs.

Figure legend

Figure 1 A primary, secondary, and tertiary prevention model of Relative Energy Deficiency in Sport (REDs). Pictures from pixabay.com.



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Scientific Contributions

MKT and AKM were responsible for leading and coordinating the manuscript. KK and JSB were responsible for drafting the section on primary prevention, AKM and MKT were responsible for drafting the section on secondary prevention, MM, KEA, BH, and NC were responsible for drafting the section on tertiary prevention. All authors were involved in the final manuscript's conception, revising, and approval before submission.

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Margo Mountjoy is a Deputy Editor of the BJSM and a member of the BJSM IPHP Editorial Board.

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No data is available.

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