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REVIEW ARTICLE

The Path Towards Progress: A Critical Review to Advance the Science of the Female and Male Athlete Triad and Relative Energy Deficiency in Sport

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Abstract
Energy status plays a key role in the health of athletes and exercising individuals. Energy deficiency/low energy availability (EA), referring to a state in which insufficient energy intake and/or excessive exercise energy expenditure has resulted in compensatory metabolic adaptations to conserve fuel, can affect numerous physiological systems in women and men. The Female Athlete Triad, Male Athlete Triad, and Relative Energy Deficiency in Sport (RED-S) models conceptualize the effects of energy deficiency in athletes, and each model has strengths and limitations. For instance, the Female Athlete Triad model depicts relationships between low EA, reproductive, and bone health, underpinning decades of experimental evidence, but may be perceived as limited in scope, while the more recent RED-S model proposes a wider range of potential health effects of low EA, though many model components require more robust scientific justification. This critical review summarizes current evidence regarding the effects of energy deficiency on athlete health by addressing the quality of the underlying science, the strengths and limitations of each model, and highlighting areas where future research is needed to advance the field. With the health and wellness of athletes and exercising individuals as the overarching priority, we conclude with specific steps that will help focus future research on the Female and Male Athlete Triad and RED-S, and encourage all researchers, clinicians, and practitioners to collaborate to support the common goal of promoting the highest quality science and evidence-based medicine in pursuit of the advancement of athletes' health, well-being, and performance.

1 Introduction

Energy status plays a key role in the health of athletes and exercising individuals. Energy deficiency/low energy availability (EA), referring to a state in which insufficient energy intake and/or excessive exercise energy expenditure has resulted in compensatory metabolic adaptations to conserve fuel, can affect numerous physiological systems in women and men. The deleterious physiological effects of chronic energy deficiency/low EA on an individual's health, performance, and well-being are important concerns for athletes and exercising individuals and, therefore, warrant thorough investigation and understanding. As such, it is necessary that all stakeholders—i.e., athletes, sports medicine physicians, athletic trainers, researchers, sports dietitians, sports psychologists, coaches, etc.—understand the current state of the science to support improvements in the health and clinical care of athletes with, and at risk for, energy deficiency/low EA. This paper provides a critical review of the strengths, limitations, and gaps in the Female and Male Athlete Triad (Triad) and Relative Energy Deficiency in Sport (RED-S) models and encourages researchers and clinicians to collaborate to support the common goal of promoting the highest quality science and evidence-based medicine in pursuit of the advancement of athlete health and well-being.

2 A Brief History of the Female Athlete Triad

The Female Athlete Triad (Triad), a syndrome characterized by the interrelated conditions of low EA, menstrual dysfunction, and compromised bone health, has been defined based on decades of scientific progress and evidence-based

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Key Points

All stakeholders—i.e., athletes, sports medicine physicians, athletic trainers, researchers, sports dietitians, sports psychologists, coaches, etc.—understand the current state of the science to support improvements in the health and clinical care of athletes with, and at risk for, energy deficiency/low energy availability.

The establishment of a causal role for low energy availability in the development of Triad and RED-S outcomes needs to be a focus of high-quality research in these areas, inclusive of randomized controlled trials and studies of long-term effects when possible.

While both the Triad and RED-S models have limitations, the advancement of the RED-S model will only be possible with rigorous experiments on non-Triad components, i.e., gastrointestinal, immunological, hematological, cardiovascular, etc., establishing causal relationships for low energy availability with these outcomes.

research. As early as the 1960s–1970s, the first scientific reports of menstrual disturbances in female athletes were published [1–4], laying the groundwork for future research delving into female-specific issues in exercise physiology. Dr. Barbara Drinkwater, a key pioneer, established the foundational understanding of the relationship between menstrual disturbances and compromised bone health in female athletes in the 1980s [5, 6]. Investigations of bone health and menstrual dysfunction continued (e.g. [7, 8]), leading to a Task Force on Women's Issues of the American College of Sports Medicine (ACSM) in 1992, where researchers and clinicians devoted to the health of exercising women gathered to critically assess the evidence for a "Triad" of clinical disorders presenting in female athletes—disordered eating, amenorrhea, and osteoporosis—and hence the term the "Female Athlete Triad" was coined [9]. With the official recognition of a syndrome of three interrelated conditions [10], rigorous scientific inquiry progressed and our understanding of the mechanisms underpinning the Triad consequently evolved. The first ACSM Female Athlete Triad position stand, published in 1997 [11], reflected the most scientifically sound Triad research available to date and described the hypothesized mechanism that low EA disrupts the hypothalamic-pituitary-ovarian axis and suppresses menstruation, and that resultant hypoestrogenemia negatively affects bone mineral density [5, 7, 12, 13].

In 2007, the position stand was updated [14] to again reflect the most current science available; based on the evidence that had emerged, the Triad model was expanded to encompass a spectrum upon which each of the Triad components ranges from healthy (optimal EA, eumenorrhea, and optimal bone health) to pathological endpoints (low EA, functional hypothalamic amenorrhea, and osteoporosis). The updated Triad model was influenced by the work of Dr. Anne Loucks, who conducted high-quality, well-controlled laboratory experiments in which induced low EA resulted in a host of endocrine and metabolic adaptations, including altered luteinizing hormone (LH) pulsatility and altered concentrations of thyroid hormones, insulin-like growth factor-1 (IGF-1), insulin, cortisol, and bone-turnover markers [15–19]. The findings by Loucks and colleagues causally linked and described endocrinological underpinnings of low EA to the clinical reproductive and bone health outcomes in the Triad model [14]. Well-designed cross-sectional and longitudinal research studies in laboratory and free-living environments further bolstered the scientific evidence supporting the updated Triad model [17, 19–30]. In line with continued advancement in the scientific and clinical understanding of the Triad, an evidence-based consensus statement establishing treatment and return to play guidelines was published in 2014 by experts in the field representing the *Female Athlete Triad Coalition* [31, 32], a non-profit 501(c)(3) organization comprising an international group of clinicians and scientists.

3 Emergence of the Relative Energy Deficiency in Sport (RED-S) Model

In 2014, authors representing the International Olympic Committee (IOC) published a consensus statement that introduced new terminology: "Relative Energy Deficiency in Sport (RED-S)" [33] (updated in 2018 [34]). RED-S, defined as "energy deficiency relative to the balance between dietary intake and energy expenditure," describes effects of low EA on reproductive and bone health, as outlined in the Triad model, as well as impairments in additional systems, including gastrointestinal (GI), immunological, hematological, growth and development, and psychological outcomes [33, 34]. This multi-system approach to the purported effects of energy deficiency is inclusive of male athletes. The RED-S model, which proposes a broader syndrome, is indeed an interesting concept that has sparked the interest of the sports medicine community.

The 2014 RED-S Consensus Statement also stated that "new terminology is required to more accurately describe the clinical syndrome originally known as the Female Athlete Triad" [33]. This language has led to confusion among stakeholders and resulted in the interpretation that the RED-S model supersedes and replaces the Triad model and

that the Triad model no longer exists as a meaningful condition or diagnosis [35]. The path forward must include the understanding that the Female Athlete Triad and the emerging model of the Male Athlete Triad exist alongside and independent of RED-S. Additionally, the Female Athlete Triad and the RED-S Consensus Statements each include a different risk stratification algorithm, leaving practitioners to have to choose which approach to use.

It is important to note that the Triad components are the most robustly supported facets of the RED-S model, and represent clinically relevant outcomes backed by scientific evidence outlined in numerous expert consensus statements for diagnosis and treatment of functional hypothalamic amenorrhea [36], eating disorders [37], and osteoporosis [38]. Furthermore, the decades of research describing the interrelationships among energy, reproduction, and bone health in exercising women, and the endocrine and metabolic adaptations to energy deficiency highlighted in the experiments by Loucks and colleagues [15–19], are foundational to the RED-S model.

As the RED-S model is relatively new, several components that differentiate RED-S from the Triad (i.e., gastrointestinal, immunological, and hematological concerns) warrant well-designed research to investigate the true causal effects of low EA on these systems and the clinical relevance of proposed outcomes. This paper is designed to identify the gaps and areas of future research for both the Triad and RED-S and provide a direction forward.

4 Energy Deficiency in Men

Research emerged in the mid 1980s–early 1990s to indicate that a subset of male athletes presented with altered reproductive hormones (i.e., testosterone, LH, prolactin) [39–42] and poor bone health [43], suggesting an effect of energy deficiency in men. While the proposition that male athletes may also suffer from reproductive and bone health impairments in response to eating disorders was introduced in the 1997 Female Athlete Triad consensus statement [11], men were not a focal point of Triad research at that time. A most noteworthy aspect of RED-S was the explicit call to investigate the effects of energy deficiency in men, highlighting that the detrimental effects of energy deficiency are not limited to exercising girls and women. In response to the call for research into energy deficiency in men, researchers convened in a round-table meeting in 2017 to discuss current evidence and the basis for a Triad-like condition in men. The resultant product was a two-part consensus statement on the Male Athlete Triad, published in 2021, which introduced the interrelationship of energy deficiency/low EA with or without disordered eating/eating disorders, functional hypogonadotropic hypogonadism, and osteoporosis or low bone mineral density with or without bone stress injuries [44, 45]. An additional result of the roundtable and emphasis on required research in men was the renaming of the Female Athlete Triad Coalition as the Female and Male Athlete Triad Coalition in 2018.

5 Gaps to be Addressed in Triad Science

Scientific progress is dependent on developing and implementing well-designed research studies, reporting and interpreting novel results, and critically examining the quality of available evidence. In the early stages of Triad research, criticisms were raised regarding causality among conditions and overstating its prevalence and importance [46–48]. Such criticisms motivated researchers to develop well-designed laboratory-based studies [16, 18, 19, 22–24, 49–52] and prospective and randomized clinical studies [27–30, 53–56] to address specific concerns and to advance Triad science. Despite significant progress since that time, the understanding of Triad physiology and clinical consequences of low EA on reproductive and bone health is still incomplete. Further research is necessary to determine: (1) long-term effects on fertility, (2) long-term effects on bone health, including the state of bone health of previously amenorrhoeic athletes when reaching the menopausal transition and beyond, (3) preventive countermeasures, and (4) timing of and capacity for reversal of clinical endpoints. Ongoing work is aimed at establishing validated field-based measures to assess metabolic compensation as an indication of chronic energy deficiency. A clear gap in Triad literature is the impact of hormonal contraceptive therapy on Triad outcomes; recent randomized controlled trials interestingly demonstrate that non-oral routes of hormonal therapy may offer benefit to bone health in amenorrheic athletes, with improvements in bone density and structure [57–59]. In addition, gonadal steroid environment may impact psychological constructs such as cognitive flexibility [60], and may also impact verbal memory [60] and eating behavior [61]. It is imperative that future research also includes efforts to understand the impact of race, ethnicity, and disability on Triad-related outcomes. An emerging area of importance extends to understanding the effects of changing hormonal dynamics in transgender individuals on Triad outcomes. Lastly, recent advances have been made with the publication of two consensus papers on the Male Athlete Triad [44, 45], and future research will continue to build the Male Athlete Triad on the scaffolding of the Female Athlete Triad model.

6 Gaps to be Addressed in RED-S Science

Given that the RED-S model is still relatively new, it is important to similarly address its scientific concerns [62, 63] utilizing evidence-based, high-quality scientific approaches to test the model and advance knowledge in several key areas. Importantly, areas of the RED-S model that require additional scientific inquiry include: (1) confirmation of direct relationships between relative energy deficiency and non-Triad aspects of RED-S, i.e., identifying causal effects of energy deficiency (independent of exercise) on hematological, gastrointestinal and immunological health, growth and development, and psychological health (detailed in sect. 6.5); (2) differentiating benign physiological adaptations (i.e., physiological plasticity) to energy fluctuations from clinically concerning endpoints of RED-S; (3) distinguishing between the consequences of clinical eating disorders versus energy deficiency as a result of nonpathological eating behaviors; and (4) quantifiable and consistent definitions of non-Triad clinical outcomes that include recognized units of measure and established processes for measurement. Such research would seek to clarify the specific physiological endpoints, their units of measure, and their clinical relevance. This sentiment is reflected throughout the article.

Both the Triad and RED-S models require more research to understand how race, ethnicity, physical disabilities, and socioeconomic status affect energy deficiency-related health outcomes. Direct sex comparisons are also needed to further characterize effects of energy deficiency on unique male and female physiology. Furthermore, validation of accurate field-based assessments of energy deficiency would benefit all Triad and RED-S research. Key features pertaining to both models are compared between the Triad and RED-S, and areas of future research are summarized in Table 1.

Below, we outline the areas of the RED-S model that require the most additional research and clarifications to further our understanding of the consequences of energy deficiency.

6.1 Hematological

The intended outcomes of concern in the hematological domain of the RED-S model are unclear. The 2018 updated RED-S consensus statement suggests iron deficiency as the hematological concern of interest, and that iron deficiency may induce low EA and low EA may contribute to iron deficiency. Supporting references are limited to one review paper in which iron deficiency was examined with respect to the components of the Triad [64]. Other investigations include a cross-sectional questionnaire study that correlated survey surrogates of low EA with self-reported history of anemia; low hemoglobin, iron, or ferritin; and/or abnormal bruising [65]; and a case series that demonstrated no change in ferritin over a competitive season [66]. More investigations are required to test causal relationships between energy deficiency and low iron. Additionally, clearer definitions of hematological outcomes of clinical concern in response to RED-S are needed to guide clinical practice.

6.2 Gastrointestinal

The RED-S model proposes that gastrointestinal (GI) health may be impacted by low EA. To date, cross-sectional studies have demonstrated associations between self-reported GI symptoms and surrogates of low EA, though direct relationships between low energy availability and GI symptoms remain to be elucidated [65, 67, 68]. The presence of GI symptoms has been assessed in RED-S research [67] by the Low Energy Availability in Female Athletes Questionnaire (LEAF-Q) [69], which includes four questions related to gas/bloating, cramps/stomachache, frequency of bowel movements, and qualities of stool; however, the experience of any one of these non-specific GI symptoms could reflect an underlying illness that is independent of energy deficiency. For example, frequent, loose stools could reflect irritable bowel syndrome (a relatively common finding in 11% of people worldwide [70]), celiac disease, lactose or gluten intolerance, GI upset related to diet composition, or an infectious process [71]. Ruling out these conditions should be an essential part of initial subject screening for GI symptoms prior to assuming they are secondary to energy deficiency. Further, there is an established literature in athletes documenting GI issues with contributing factors inclusive of mechanical forces and neuroendocrine changes [72], altered blood flow [73, 74], "leaky gut" [75, 76], and inflammatory bowel disease [77]. As with the hematological outcomes, evidence from prospective experimental studies is needed to improve understanding of the relationship between low EA and GI health.

6.3 Immunological

Similar to the hematological and GI domains of the RED-S model, there is limited evidence to support a direct link between energy deficiency and immune function in athletes [63, 78], and in fact there are randomized trials that demonstrate that caloric restriction in healthy adults improves immunity [79]. Indeed, rarely have researchers linked immune responses in athletes to a clinically diagnosed illness, as most associations have also been based on self-report [80, 81] or have failed to objectively define illness [82–84]. Self-reported illness associated with survey-based surrogate measures of low EA suggest a need for further study into direct mechanisms linking EA and immune function [65, 67, 68]. Future studies must also take into account

Table 1 Key features and future research areas for the Female and Male Athlete Triad (Triad) and Relative Energy Deficiency in Sport (RED-S) models

	Female Athlete Triad	RED-S
Date of first position stand and updates	1997 [11], 2007 [14], 2014 [31, 32]	2014 [33], 2018 [34]
Key features		
Quality of evidence	Supported by laboratory experiments, observational studies, and randomized controlled trials [17, 19–30, 55, 56]	Non-Triad components supported by self-reported survey data from observational studies [65–68] and cross-sectional studies [105–107]. Triad-related components investigated with randomized controlled trials [98–100] and cross-sectional studies [108–110]
Causal role for low energy availability/energy deficiency	Determined for reproductive and bone outcomes using laboratory experiments in humans and animal models [17–19, 27, 29, 30, 55]	Not yet established for non-Triad components
Clinical relevance of outcomes	Demonstrated for eating disorders, functional hypothalamic amenorrhea, and low bone mass as evidenced by differential diagnoses, individual position stands in each of the three areas [36–38]; illustrates progression of severity from healthy to pathological	Not yet established for non-Triad outcomes
Quantification of outcomes	Units of measure and terminology are specific to the outcome	Not yet established for non-Triad outcomes
Diagnostic criteria for outcomes	Provided for eating disorders, menstrual disturbances, and determination of low bone mass [31, 32]. Diagnostic criteria not yet established for low energy availability but emerging evidence for energy deficiency (RMR ratio) [51, 52]	Not yet established for non-Triad outcomes
Population of interest	Female, but recently, separate scientific and clinical consensus statements written for Male Athlete Triad [44, 45]	Inclusive of men, calls for more research into effects of energy deficiency on individuals from different racial and ethnic backgrounds and individuals with disabilities [33, 34]
Athletic performance as an outcome	Not included	Athletic Performance Outcomes Included [104]
Risk stratification algorithm	Included [31, 32]	Included [33]
Reversibility established	Established for reproductive and energy spectra [14, 30, 49, 55], but recent randomized controlled trial [56] reports that 1 year of modest nutritional therapy is not successful in restoring bone density in exercise women with oligo/amenorrhea	Not yet established for non-Triad outcomes
Areas for future research		
Inclusion of individuals from varied races, ethnicities, and abilities	Much needed; the effects of the Triad in youth and adult vs peri/menopausal/postmenopausal women have not been evaluated	Much needed; the effects of the non-Triad outcomes in youth and adult vs peri/menopausal/postmenopausal women have not been evaluated
Effects of low energy availability/energy deficiency in men	Growing data on effects of reproductive function, bone health, but more research is needed inclusive of head-to-head sex comparisons	Presented in RED-S model, Triad-related components investigated with randomized controlled trials [98–100]; more research needed inclusive of head-to-head sex comparisons
Effects of hormonal contraceptives	More research needed; controversial findings exist for effects of hormonal therapy on bone; some new data on route of administration effects [57–59], and effects on eating behavior of hormonal therapies [61]	Not established for non-Triad outcomes
Long-term effects of low energy availability on outcomes	The research supporting the Triad has not explicitly examined future implications on fertility; long-term studies also needed on bone outcomes	Research needed on long-term effects of non-Triad outcomes
Risk stratification algorithm	Updating needed to include additional measures and test ability to accurately predict outcomes	Updating needed to include additional measures and test ability to accurately predict outcomes; updating needed on specific definitions of outcomes, their quantification, and units of measurement where appropriate

Table 1 (continued)

	Female Athlete Triad	RED-S
Prevention, treatment, and recovery	More education of sports medicine stakeholders still necessary, as well as refinement of nutritional therapy and hormonal therapy approaches	More education of sports medicine stakeholders still necessary, as well as refinement of nutritional therapy and hormonal therapy approaches
Causal role for low energy availability/energy deficiency	Established for reproductive and bone health outcomes [27, 29, 30, 55], but surrogate measures for energy availability that can be accurately measured in the field are needed	Needs to be established for non-Triad outcomes for men and women, and surrogate measures for energy availability that can be accurately measured in the field are needed

the general incidence of diseases, such as the common cold, influenza, and viral respiratory illnesses [85], and consider factors such as the seasonality of these illnesses [86, 87], housing conditions during Olympic competitions, or the risk associated with contracting illness during air travel, which may be common in athletes competing at high levels [88, 89]. Controlling for these numerous confounding factors is necessary to definitively demonstrate a causal relationship between energy deficiency and immune function.

6.4 Growth and Development

The 2018 RED-S updated consensus statement describes the "growth and development" domain of the model as encompassing the growth hormone (GH)/IGF-1 axis, citing anorexia nervosa literature and studies in amenorrheic athletes [90–95]. The authors point out a need for more research to understand implications of known physiological adaptations of the GH/IGF-1 axis on training and growth. The implication of the acquired state of GH resistance in conditions of EA beyond its impact on bone remains unclear.

6.5 Psychological

The relationship between psychology and energy deficiency is complex. It is well-documented that psychological constructs, such as a high drive for thinness and dietary cognitive restraint, result in eating behaviors that contribute to developing energy deficiency. However, the effect of energy deficiency on psychology is less well understood. Distinguishing whether energy deficiency can directly cause psychological impairments or exacerbate existing psychological impairments is warranted, and results of such studies will inform multidisciplinary treatment strategies in those with low EA and psychological disturbances.

7 Delineating Correlation from Causation

As mentioned, much of the current research assessing non-Triad outcomes of low EA proposed by RED-S is limited to correlational and self-report survey data. In some studies, energy status is not adequately measured, and yet individuals are presumed to be energy deficient based on the presence of a proposed physiological outcome. For instance, in a recent study by Rogers et al. [67] assessing the prevalence of RED-S symptoms, survey data suggested that 80% of athletes had RED-S, defined as any single component of the proposed outcomes of RED-S, with particularly high rates of impaired GI and immune function (> 30%). Despite a high rate of suggested RED-S outcomes, there was a very low prevalence of physiological indications of energy deficiency in the sample (i.e., only three of 107 individuals had a Cunningham resting metabolic rate ratio < 0.90) [67]. As such, it is unlikely that the GI and immune outcomes were actually a result of energy deficiency in this investigation. Thus, this study and others [65, 68, 96] do not provide causal evidence for a link between energy deficiency/low EA and GI or immune function, but rather imply that participants are in an energy-deficient state despite limited or no physiological evidence of energy deficiency. Importantly, evidence of an effect is not evidence of the cause, and evidence of two variables existing in the same group of individuals is not evidence that the two variables are at all related.

In order to move beyond correlational findings, more rigorous research study designs are needed to improve the overall quality of RED-S-related evidence [63, 97]. For instance, prospective experiments in which energy intake and expenditure are manipulated and specific outcomes are measured (i.e., GI or immune function) would be informative to determine direct effects of energy deficiency. Previous investigations that used short durations of EA perturbations (e.g., 4–5 days) [16–19, 98–101] provided fundamental causal evidence relating energy deficiency to surrogate measurements of metabolic, reproductive, and bone outcomes in men and women. Similar study designs can be utilized to investigate the additional RED-S outcomes and would provide important information regarding the causality and timing of effects of energy deficiency. Short-term studies would pave the way for longer-duration investigations or randomized controlled trials (RCTs) that mirror training cycles or other relevant time frames to further elucidate temporality. Importantly, in these studies, confounding etiologies contributing to the proposed effects of energy deficiency need to be assessed or

explicitly controlled for. For instance, pre-existing medical conditions (e.g., screening for hyperandrogenism and other endocrinopathies), indirect effects of energy deficiency due to changes in estrogen, the physical stress of exercise itself, overtraining, training seasonality, micronutrient deficiencies, and macronutrient distribution may all contribute to physiological impairments as indirect effects of energy deficiency or even independent of energy deficiency, and should be considered. All scientists must be careful to assure that the message interpreted by the lay public is based on the best quality evidence. For certain facets of negative physiologic impact proposed by the RED-S model, such high-quality evidence has not, as of yet, been achieved. This creates a gap in knowledge and science that needs to be addressed, and also the risk that non-evidence-based messaging may perpetuate unsubstantiated fears in coaches, sports medicine practitioners, and other consumers. It is most appropriate to be concerned about the health consequences of energy deficiency, but assuming that common physiological impairments in athletes are all underpinned by energy deficiency can be misleading and further complicate proper medical evaluation, diagnosis, and treatment for athletes who may be truly experiencing an underlying condition independent of energy deficiency. Caution should be taken to avoid over-interpreting certain outcomes that could be used as surrogate markers, i.e., the use of LH pulsatility to indicate reproductive dysfunction, or the use of bone markers to indicate bone health, which should not be used to make direct statements on overall reproductive function or bone health. These surrogate markers cannot replace the use of long-term studies that assess menstrual cycles, bone density, or bone geometry when trying to claim effects of an independent variable such as energy deficiency on these clinically important outcomes.

8 Conclusion—Next Steps for the Field

With more research necessary to further understand the complex and widespread effects of energy deficiency, it is essential to recognize that a unifying interest exists: *the health and wellness of athletes and exercising individuals. Just as RED-S does not replace the Triad, the Triad model does not preclude the existence of other potential physiological effects of energy deficiency as proposed by RED-S. Both the Triad and RED-S models can exist simultaneously, and the contributions, limitations, and advancements of each model deserve acknowledgement and recognition.*

It is useful to recall that criticism during the early days of Triad research [46–48] sparked the necessary advancement and continued progression of our current understanding of the interrelationships among energy deficiency/low EA, reproductive dysfunction, and impaired bone health in exercising women. Thoughtful debate and critical discussion can serve as positive forces to continue to advance scientific rigor regarding Triad and RED-S health consequences, and thereby effectively address the health issues that are of most clinically relevant concern to athletes and

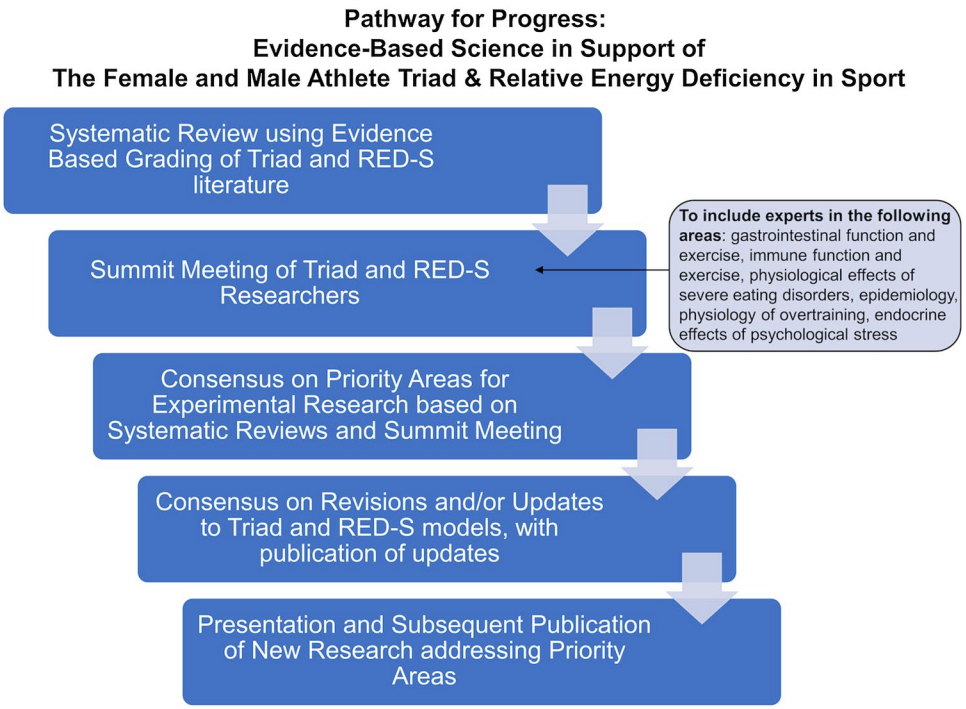

Fig. 1 A proposed schematic for the progression of Female and Male Athlete Triad and Relative Energy Deficiency in Sport research

exercising individuals. To this end, a suggested "pathway for progress" is illustrated in Fig. 1. It is suggested that systematic reviews be published using evidence-based grading strategies to assess the current status of Triad and RED-S literature. Validated approaches to achieve consensus are needed, and one that may be considered as a framework is the RAND modified-nominal group technique (NGT) [102]. This approach incorporates the independent anonymous structure of the Delphi method [103] with the ability to assemble (potentially remotely given our COVID-era technological flexibility) to encourage clarification and discussion. Consensus could lead to modifications of the Triad and RED-S models and spur new research addressing priority areas. Modification of the models that recognizes a hierarchy of clinical outcomes of most urgent concern when assessing athletes with energy deficiency is likely necessary. *Progress ultimately requires that Triad and RED-S researchers and clinicians acknowledge and work toward the common goal to promote the best and highest quality science and evidence-based medicine in a cohesive manner.*

Declarations

Conflict of interest Mary Jane De Souza, Nicole C. Strock, Emily A. Ricker, Kristen J. Koltun, Michelle Barrack, Elizabeth Joy, Aurelia Nattiv, Mark Hutchinson, Madhusmita Misra, and Nancy I. Williams declare that they have no conflicts of interest relevant to the content of this article.
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