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*KOSALB International Journal of Human Movements Science, Vol: **4**, No: **2**, **2025**, p **73-86**, DOI: **10.70736/2958.8332.kosalb.65** | ISSN: **2958-8332** | Published: **27.12.2025***

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Review Article

The Multidimensional Impact of Energy Deficiency and Low Energy Intake on Elite Female Athletes: A Systematic Review

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Authors' Contribution: A: Study design, B: Data collection, C: Data analysis, D: Manuscript preparation, E: Discussion and conclusion

ABSTRACT

Study aim(s): This systematic review aims to provide a comprehensive examination of the multifaceted effects of low energy availability (LEA) and its progression to sport-related Relative Energy Deficiency in Sport (RED-S) on performance, recovery, injury risk, and long-term health outcomes in elite female athletes.
Methods: This study was conducted as a systematic review in accordance with PRISMA standards. A comprehensive literature search was performed using keywords such as "RED-S," "LEA," "elite female athletes," "performance," "recovery," "injury risk," and "long-term health". Methodological quality and risk of bias (RoB) were assessed using appropriate tools, including the Cochrane RoB for randomized controlled trials and the Newcastle-Ottawa Scale for observational studies. Findings were then thematically synthesized into four primary domains: performance, recovery and metabolic function, injury risk, and long-term health.
Results: The findings consistently demonstrate that LEA, the primary cause of RED-S, has significant adverse effects across multiple physiological systems. High prevalence rates of LEA and RED-S risk have been reported across various sports, particularly in aesthetic and endurance disciplines (e.g., 77.4% in football, 80% in athletes exhibiting at least one RED-S symptom across sports, and 41.6% in aesthetic sports). Key consequences include metabolic slowing, hormonal axes disruption, decreased bone mineral density, impaired vascular function, and an increased risk of both bone and soft tissue injuries. Furthermore, LEA and RED-S are associated with reduced power output and impaired recovery capacity, posing a serious threat to performance sustainability and career longevity.
Conclusions: LEA is a key precursor to RED-S, presenting a significant multisystemic threat to the health and performance of elite female athletes. The well-established connection between LEA-induced energy deficits and serious physiological consequences underscores the need for early diagnosis and a structured, multidisciplinary management approach. Future research should focus on longitudinal study designs, standardized measurement protocols, and the identification of sport-specific energy availability thresholds to clarify causal relationships and inform evidence-based clinical practice.

Keywords: Relative Energy Deficiency Syndrome, Low Energy Availability, Elite Female Athletes Performance, Injury Risk, Long-Term Health

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KOSALB International Journal of Human Movements Science, Vol: 4, No: 2, 2025, p 73-86, DOI: 10.70736/2958.8332.kosalb.65 | ISSN: 2958-8332 | Published: 27.12.2025
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INTRODUCTION

Relative Energy Deficiency in Sport (RED-S) is a condition that arises in athletes when energy intake fails to meet energy expenditure, resulting in functional impairments across multiple physiological systems [1, 2]. Energy availability is defined as the energy consumed through diet minus the energy expended during exercise, relative to lean body mass. When energy availability falls below a critical threshold, the body lowers metabolic rate to maintain essential functions and suppresses energy-demanding systems, including reproduction, growth, bone mineralization, immunity, and hormonal regulation [2,3]. Thus, RED-S should not be considered simply as energy starvation, but rather as a systemic adaptive response prioritizing the organism's survival. Low Energy Availability (LEA), defined as a state in which an athlete's dietary energy intake is insufficient relative to the energy expended during training, represents the primary physiological trigger of RED-S.

The conceptual foundation of RED-S was initially developed within the framework of the Female Athlete Triad, which encompasses low energy availability, menstrual dysfunction, and reduced bone mineral density [4]. However, consensus statements from the IOC now indicate that RED-S can impact multiple physiological systems, including metabolic, endocrine, immune, cardiovascular, hematological, psychological, and gastrointestinal functions [5]. This broad impact underscores that RED-S is not only associated with short-term performance issues but also carries significant long-term health implications. The multidimensional effects of LEA highlight that RED-S influences a wide range of metabolic, endocrine, neurological, and performance-related systems.

Elite female athletes are particularly vulnerable to RED-S due to a combination of physiological and sociopsychological factors. High training volumes, performance goals emphasizing lean body mass, the advantages of low body weight in certain sports, and aesthetic or formal expectations all contribute to the development of low energy availability [6]. Furthermore, aesthetic pressures from social media and sports culture can increase the risk of disordered eating and further restrict energy intake in female athletes [7]. These effects comprise both the physical and psychological health of athletes, resulting in reduced performance and diminished quality of life. Low energy availability disrupts hormonal cycles, impairs bone remodeling, and contribute to decreased bone mineral density [8]. Stress fractures related to RED-S are more common among young elite athletes, particularly in aesthetic and high-load sports at an early age [3]. The decline in bone health extends beyond reduced mineral density, also affecting bone microarchitecture and prolonging the healing of stress-related fractures [9]. Furthermore, low energy availability can have lasting health consequences, increasing the long-term risk of osteoporosis and fractures. In elite female athletes, the development of LEA is often linked to behavioral and sociopsychological factors, including intentional or unintentional energy restriction, pressure to maintain a lean physique, and performance-oriented body composition goals.

RED-S can directly affect performance, with the effects most pronounced in activities requiring sprinting, jumping, and short-term, high-intensity exertion [10]. Impaired recovery further contributes to the accumulation of microtrauma and an increased risk of soft tissue injuries [11]. Together, these mechanisms indicate that RED-S is a critical factor influencing both performance and injury risk, particularly in power- and explosiveness-sports. Chronic LEA disrupts hormonal cycles and suppresses bone mineralization, negatively affecting bone density as well as bone microarchitecture.

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RED-S may increase risk by altering connective tissue and ligament biomechanics through associated hormonal changes. Fluctuations in estrogen levels affect connective tissue elasticity and joint stability, increasing susceptibility to injuries such as anterior cruciate ligament (ACL) tears [12,13]. These findings suggest that RED-S impacts not only bone health but also musculoskeletal and ligament integrity. Additionally, the insufficient energy and nutrient intake associated with LEA reduces muscle glycogen stores and impairs adaptation to training stimuli, directly compromising high-intensity performance.

Most of the existing literature has focused on endurance athletes, and studies examining the performance, recovery, and injury-related outcomes of RED-S remain limited [6]. Furthermore, much of the research on the long-term health effects of RED-S and LEA relies on cross-sectional designs, highlighting the need for studies to establish causal relationships. Consequently, a comprehensive systematic review examining the effects of RED-S and LEA on performance, physiological function, recovery processes, injury risk, and long-term health outcomes in elite female athletes is needed.

METHODS

Research design

This study was conducted as a systematic review in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards. Its aim was to provide a comprehensive evaluation of the effects of Relative Energy Deficiency in Sport (RED-S) on performance, recovery, injury risk, and long-term health in elite female athletes, while also identifying gaps within the existing literature.

Data Analysis and Thematic Synthesis

In this systematic review, the findings of the included studies were analyzed using a thematic synthesis approach, with attention to the research question, the physiological effects of RED-S, and its implications for athlete performance. Population characteristics, sport type, energy availability assessment methods, and reported performance and health outcomes were first systematically extracted into a structured data extraction form. Studies showing similar result patterns were then evaluated comparatively based on principles of conceptual similarity and redundancy. This analytical process revealed that the findings clustered significantly into four main themes:

Performance Effects:

Studies investigating the impact of low energy availability on power production, explosive performance, and responsiveness to training.

Recovery and Metabolic Functions:

Studies reporting outcomes related to metabolic rate, recovery duration, psychological stress, and overall energy regulation.

Injury Risk and Musculoskeletal Health:

Studies demonstrating the relationship between LEA/RED-S and musculoskeletal outcomes, including fractures, soft tissue injuries, and ligament and tendon strength.

Long-Term Health and Hormonal/Bone Effects:

Studies investigating the long-term physiological consequences of LEA/RED-S, including impacts on hormonal axes, menstrual function, bone mineral density, and cardiovascular function.

Thematic separation was used to clarify the scope of the research question, present findings more clearly, and enhance interpretability from a clinical and practical perspective. This approach aligns with the multidimensional nature of RED-S research in

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sport sciences and is based in qualitative data synthesis in accordance with PRISMA guidelines.

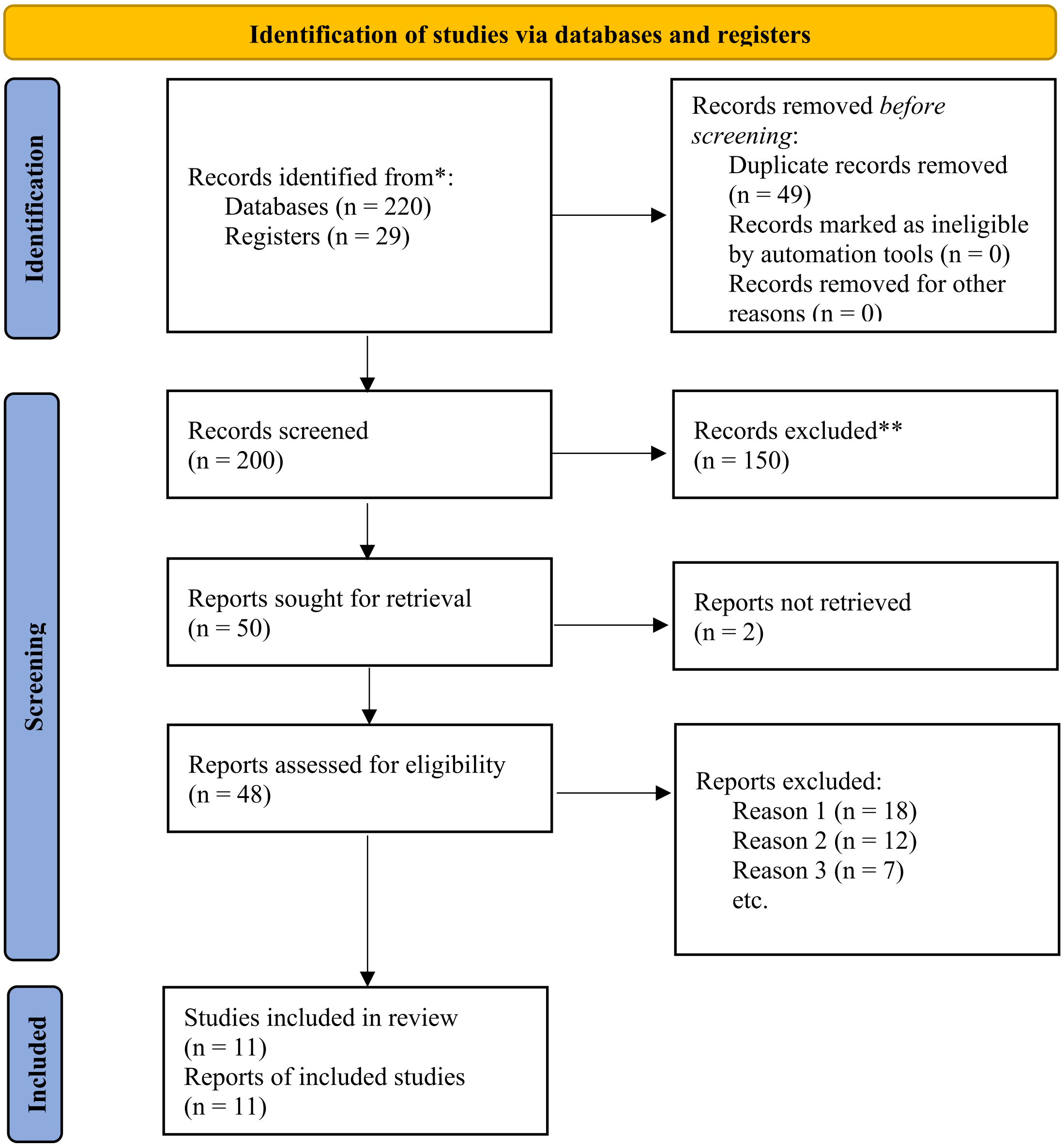

Figure 1. PRISMA 2020 flow diagram

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Table 1. Risk of Bias Assessment of Studies on LEA and RED-S in Female Athletes

Authors, Year	Sport Branch	Method (design, sample, tools)	Main Findings	RoB
[21]	Football	Prospective cohort. 46 women, 15–26 years LEAF-Q, OSTRC-H, 3-day food and exercise diary, DXA	77.4% reported low energy intake; high incidence of injury and illness; LEAF-Q scores associated with injury risk	Middle
[14]	Various sports	Cross-sectional. 112 women, 15–32 year LEAF-Q, RMR, DXA, blood tests, MINI 7.0.2	80% had at least one RED-S symptom, 37% had 2–3 symptoms; RMR and LEAF-Q indicated risk of low energy intake	Middle
[20]	Dance	Cross-sectional. 50 women, 19.8 ± 4.1 year LEAF-Q, EAS, anthropometry, logistic regression	Low energy intake, age, BMI, and BF% were associated with soft tissue injuries, whereas exposure duration was linked to bone injuries.	Middle
[23]	College sports	Cross-sectional. No information given REDs CAT2	RED-S risk assessment, identification of athletes at risk	Middle
[16]	Professional handball	RCT. 21 women, 22 ± 4 year LEAF-Q, 7 daily diet analysis, BIA, anthropometry, blood tests, strength test	Low energy intake (<30 kcal/kg FFM); all athletes maintained eumenorrhea; significant improvements in body composition; no significant differences in other variables	Low
[15]	Aesthetic sports	Cross-sectional. 166 women, 20 ± 2 year LEAF-Q, EDI-3 RF, body composition measurements	41.6% at risk of LEA, with higher risk in elite athletes; associated with low BMD and reduced estrogen levels	Middle
[18]	Running	Cross-sectional. 18 women, 16.8 ± 0.9 year. LEAF-Q, 7 daily diet and exercise diary, DXA, RMR measurement	RMR did not decrease with low EA, indicating that RMR is an unreliable proxy for low energy intake	Middle
[19]	College sports	Cross-sectional. 100 women, 18–22 age. LEAF-Q, surveys	Risk of low energy intake was associated with increased anxiety	Middle
[13]	Team sports	Cross-sectional. 75 women. LEAF-Q, nutrition information survey	High risk of low energy intake; inadequate nutritional knowledge reported	Middle
[22]	Long distance running	Cross-sectional, controlled. 16 women elite runner, 17 control. LEAF-Q, DXA, FMD, PWV, CAR %, cIMT, blood biomarkers	44% at risk of RED-S based on LEAF-Q; vascular function remained normal	Middle
[11]	NCAA DIII swimmers	Cross-sectional. 30 women. LEAF-Q, food diary, BIA	43% reported low energy intake, with inadequate calorie and macronutrient consumption	Middle

Risk of Bias (RoB)

To provide a general assessment of the studies in Table 1 in terms of methodology and risk of bias (RoB), most studies were cross-sectional in design. This design offers advantages in data collection and sample size but limits the ability to infer causality. The reliance on self-reported questionnaires and diet/exercise diaries introduces a potential for information bias. Prospective cohort studies, while allowing for the monitoring of changes over time, carry a moderate RoB due to small sample sizes and some missing data. In contrast, the randomized controlled trial included in the review is methodologically the strongest, benefiting from an intervention and control group as well as objective measurements, and was assessed as having a low RoB.

Most studies used validated measurement tools, including the LEAF-Q, DXA, RMR, and OSTRC-H, which helps reduce measurement bias. However, limitations such as self-reporting and missing data still present risks. Variability in sample size and sport type further leads to high heterogeneity. Overall, while the adverse effects of low energy intake on health and performance were consistently observed, the generalizability of these findings is limited due to the limitations of cross-sectional designs. This assessment highlights the methodological differences and quality limitations across the studies included in this review.

RESULTS

Table 2. Data Extraction of Included Studies on the Effects of LEA and RED-S on Performance

Authors, Year	Population	Sport Branch	RED-S / LEA Evaluation Method	Performance-Related Findings
[16]	Professional female handball players	Handball	Controlled reduction of energy intake (Randomized Controlled Trial) + physical performance tests	Significant reductions in maximal power and explosive performance were observed under conditions of low energy availability, highlighting the direct impact of energy intake on performance outcomes.
[14]	Elite and pre-elite female athletes	Athletics, team sports and aesthetic sports	RED-S clinical sign screening protocols + hematological, hormonal, and metabolic indicators	Endocrine and metabolic disruptions associated with RED-S indirectly reduce performance potential.
[11]	NCAA Women's Swimmers	Swimming	Energy availability calculation (energy intake + training load) + pre-season nutrition record	Low energy availability is highly prevalent during the preseason and is associated with reduced training tolerance and impaired recovery.
[18]	Competitive young female runners	Athletics (middle-long distance)	Energy availability calculation + Resting Metabolic Rate (RMR) measurement	Low energy availability is associated with a significant reduction in RMR, reflecting a physiological slowdown that can impair performance capacity.

The studies summarized in Table 2 demonstrate that low energy availability (LEA) and RED-S have multifaceted and significant effects on performance in elite female athletes. Controlled energy restriction protocols reveal significant reductions in neuromuscular outputs, including maximal power production and explosive performance, under conditions of low energy availability. Observational studies indicate that endocrine, metabolic, and hematological disruptions

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associated with RED-S indirectly impair performance, leading to decreased training tolerance, poor recovery, and disrupted physiological homeostasis.

Furthermore, the decrease in resting metabolic rate associated with LEA suggests that the body adopts a general energy-saving mode, which may limit long-term performance potential. These findings emphasize that adequate energy intake is essential not only for health but also for maintaining sustainable performance.

Table 3. Data Extraction of Included Studies on the Effects of LEA and RED-S on Recovery and Metabolic Function

Authors, Year	Population	Sport Branch	RED-S / LEA Evaluation Method	Findings Regarding Recovery & Metabolic Functions
[18]	Competitive female youth runners (adolescents)	Athletics (middle-long distance)	Energy availability calculation + Resting Metabolic Rate (RMR) measurement	Low energy availability is associated with a significant decrease in RMR. This metabolic slowdown impairs post-exercise recovery and increases the risk of chronic fatigue.
[19]	College-level female athletes	Multi-branch	LEA risk screening scale + psychological stress and anxiety indices	Althletes at high risk of LEA exhibited significantly higher levels of anxiety and psychological stress, which have been identifies as factors that delay recovery.
[11]	NCAA women's swimmers	Swimming	Pre-season nutrition record + energy availability calculation	Inadequate energy intake can prolong recovery during periods of intense training and increase the risk of overload syndrome. A clear relationship has been demonstrated between metabolic function and post-training recovery.
[13]	Female team athletes (volleyball/basketball, etc.)	Team sports	Nutrition knowledge level + LEA assessment scales	Athletes with low nutritional awareness are at higher risk of LEA, which may negatively affect post-training recovery, muscle glycogen regeneration, and hormonal balance.

The studies summarized in Table 3 indicate that low energy availability (LEA) and RED-S significantly affect recovery processes and metabolic function. The reduction in resting metabolic rate associated with LEA reflects a metabolic conservation state, which slows recovery and increases the risk of chronic fatigue. Additionally, athletes at high risk of LEA show elevated psychological stress and anxiety, which further delay recovery through both physiological and psychological pathways. During periods of intense training, inadequate energy intake prolongs recovery, increases the risk of overload syndrome, and disrupts metabolic function. Athletes with lower nutritional awareness are particularly vulnerable to LEA, which can compromise recovery by impairing glycogen replenishment, hormonal balance, and overall regenerative capacity. Collectively, these findings highlight that adequate energy availability is essential for optimal physiological and psychological recovery.

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Table 4. Injury Risk and Effects on Musculoskeletal Health

Authors, Year	Population	Sport Branch	RED-S / LEA Measurement Method	Injury/Musculoskeletal Health Findings
[20]	Competitive female dancers	Aesthetic art-dance performance	LEA rating scale + injury records	Soft tissue injuries and injury recurrence were significantly higher in athletes with low energy availability. RED-S was also associated with reduced connective tissue and muscle recovery capacity.
[21]	Female football players	Football	Relationship between energy intake and training load + injury reporting	Athletes with higher levels of LEA experienced a greater incidence of in-season injuries, with lower extremity tendon and ligament injuries particularly associated with RED-S.
[15]	Chinese elite and recreational aesthetic athletes	Artistic gymnastics, rhythmic gymnastics, ice skating	LEA risk assessment tool	The risk of LEA is particularly high in aesthetic athletes, and RED-S has been linked to suppressed bone turnover, increasing the risk of stress fractures.
[13]	Women's team athletes (elite/semi-elite)	Volleyball, basketball, handball, etc.	Nutrition knowledge level + LEA screening	Athletes with limited nutritional knowledge are at higher risk of LEA, which is associated with prolonged recovery times and a cycle of recurring injuries.
[14]	Elite and pre-elite female athletes	Multi-branch	RED-S clinical symptom assessment + biological indicators	Hormonal and metabolic disruptions associated with RED-S are linked to decreased bone mineral density and a higher risk of stress fractures.

The studies summarized in Table 4 demonstrate that low energy availability (LEA) and RED-S exert significant and multifaceted effects on injury risk and musculoskeletal health. Athletes with higher levels of LEA show significantly increased rates of soft tissue, tendon, and ligament injuries, along with higher injury recurrence, indicating impaired connective tissue resilience and reduced muscle repair capacity. The notably high prevalence of LEA among aesthetic athletes contributes to suppressed bone turnover and an elevated risk of stress fractures. In team sport athletes, limited nutritional knowledge and the resulting risk of LEA are linked to prolonged recovery times and cycles of recurring injuries. Furthermore, hormonal and metabolic disturbances associated with RED-S contribute to reductions in bone mineral density, further increasing susceptibility to stress fractures. Collectively, these findings underscore that LEA and RED-S not only impair performance but also directly compromise musculoskeletal integrity and elevate overall injury risk.

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KOSALB International Journal of Human Movements Science, Vol: ***4****, No:* ***2****,* ***2025****, p* ***73-86****, DOI:* ***10.70736/2958.8332.kosalb.65*** *| ISSN:* ***2958-8332*** *| Published:* ***27.12.2025***

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Table 5. Long-Term Health Effects

Authors, Year	Population	Sport Branch	RED-S / LEA Evaluation Method	Findings Regarding Long-Term Health
[24]	Elite and pre-elite female athletes	Multi-branch	RED-S clinical sign screening protocols + hormonal and hematological indicators	A high prevalence of physiological impariments consistent with RED-S was observed. Hormonal suppression and metabolic adaptations were shown to contribute to long-term bone density loss and menstrual irregularities.
[23]	Competitive collegiate female athletes	Multi-branch	RED-S CAT2 risk assessment tool	The CAT2 tool was validated for detecting RED-S and was found to be particularly effective in assessing risk related to menstrual function and bone health.
[22]	Norwegian elite female runners	Athletics (middle-long distance)	Vascular function tests (FMD etc.) + energy availability assessment	Vascular function was impaired in athletes at risk of LEA/RED-S, suggesting that RED-S may cause long-term adaptations in the cardiovascular system.
[15]	Female sample of elite and recreational aesthetic athletes	Artistic gymnastics, rhythmic gymnastics, ice skating	LEA risk assessment tool	The risk of LEA is particularly high in aesthetic athletes and has been associated with suppressed bone remodeling and an increased risk of stress fractures.

The studies summarized in Table 5 indicate that low energy availability (LEA) and RED-S can have serious, multidimensional long-term health consequences. Hormonal suppression, menstrual irregularities, and reductions in bone mineral density associated with RED-S increase the risk of lasting skeletal health impairments. Additionally, validated assessment tools such as the RED-S CAT2 have proven strong utility in monitoring menstrual function and bone health, highlighting their importance for early detection and follow-up in at-risk athletes. Observed impairments in vascular function among athletes at risk of LEA/RED-S risk indicate that the syndrome may affect not only skeletal and hormonal systems but also the cardiovascular system. In aesthetic athletes, the high prevalence of LEA and the associated suppression of bone remodeling create a long-term vulnerability to stress fractures. Collectively, these findings demonstrate that RED-S and LEA affect not only short-term performance and recovery but also represent significant risk factors with potential lifelong implications for athletes' health.

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KOSALB International Journal of Human Movements Science, Vol: 4, No: 2, 2025, p 73-86, DOI: 10.70736/2958.8332.kosalb.65 | ISSN: 2958-8332 | Published: 27.12.2025

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DISCUSSION

The findings of this systematic review demonstrate that Relative Energy Deficiency in Sport (RED-S) has multidimensional effects on performance, recovery, injury risk, and long-term health in elite female athletes. Consistent with the IOC definition, a mismatch between energy intake and training load leads not only to metabolic imbalance but also to systematic changes in hormonal, physiological, and psychological functions [1]. The studies included in this review indicate that the risk of RED-S is particularly pronounced in female athletes facing high performance expectations and aestheti or performance-related pressures [14,15].

Studies examined under the performance theme indicate that low energy availability directly impairs power production, muscle contraction efficiency, and neuromuscular endurance. Notably, a randomized controlled trial by Miralles-Amorós et al. (2023) on professional female handball players confirms that reduced energy intake led to significant declines in maximal power and explosive performance [16].

The recovery and metabolic function theme suggests that the effects of RED-S extend beyond immediate performance deficits, impacting metabolic rate, hormonal regulation, and psychological stress responses. Kinoshita et al. (2021) reported that athletes with low energy availability exhibited decreased resting metabolic rates, prolonged recovery times, and hieghtened fatigue susceptibility [17]. Similarly, Scheid et al. (2024) found that low energy availability is associated with increased anxiety and psychological stress levels, further slowing physiological recovery [18]. These findings suggest that RED-S is both a physical and psychobiological syndrome.

Studies on injury risk and musculoskeletal health indicate that RED-S leads to deterioration in connective tissue strength, tendon elasticity, and bone microarchitecture. Research by Prus et al. (2022) and Elliott (2023) demonstrated that athletes with low energy availability exhibit a significantly higher incidence of recurrent soft tissue injuries and stress fractures [19,20]. Meng et al. (2020) demonstrated that the high prevalence of LEA in aesthetic sports suppresses bone remodeling, highlighting that RED-S poses a critical threat to long-term musculoskeletal health [15]. These findings align with the established Female Athlete Triad model, in which the coexistence of amenorrhea, low bone mineral density, and low energy availability collectively increases the risk of skeletal deterioration [4]. Finally, when examining long-term health outcomes, RED-S appears to have broad physiological consequences, including menstrual dysfunction, reductions in bone mineral density, impaired vascular function, and potential long-term cardiovascular effects. Kyte et al. (2022) demonstrated reduced vascular function in elite female runners with low energy availability and suggested that this may contribute to an increased lifetime cardiovascular risk [21]. These results demonstrate that RED-S is a syndrome with implications that extent beyond athletic performance, affecting overall health and well-being throughout the athlete's life.

Overall, the findings of this review highlight the need for early diagnosis of RED-S, regular monitoring of energy balance, and sport-specific nutritional planning. A multidisciplinary support model – integrating coaches, dietitians, sports medicine physicians, and psychologists – appears to be the most effective preventative approach, particularly for female athletes who face heightened physchologican and sociocultural risk factors. In this context, future research should incorporate standardized performance measurements and longitudinal follow-up designs.

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CONCLUSIONS

This systematic review has revealed that Low Energy Intake (LEA) underlies Relative Energy Deficiency Syndrome (RED-S) in elite female athletes, with broad and clinically significant implications for performance, recovery, injury risk, and long-term health. The findings indicate that reductions in energy availability triggered by LEA not only leads to short-term performance decrements but also provoke extensive physiological consequences, including metabolic slowdown, hormonal axis disruption, decreased bone mineral density, and impaired connective tissue strength. The risk of developing LEA, and consequently RED-S, is particularly pronounced in sports with substantial training loads, aesthetic demands, and intense competitive pressure. This poses a critical threat to female athletes' performance sustainability, tolerance to in-season loads, and long-term career continuity.

Research findings clearly support the need for a multidisciplinary approach to the early diagnosis and management of RED-S. It is crucial for coaches to plan training loads in accordance with athletes' energy availability, for athletic dietitians to develop individualized nutrition strategies, for sports medicine physicians to closely monitor hormonal and metabolic indicators, and for psychological support to be integrated into the process – especially in aesthetic and high-pressure sports. Furthermore, assessing energy balance solely through weight and body composition is insufficient; comprehensive monitoring of performance, recovery, menstrual function, and injury history is strongly recommended.

In this context, future studies should prioritize longitudinal follow-up designs, standardized performance assessments, the identification of sport-specific energy availability thresholds, and the development of models that further examine the psychobiological dimensions of RED-S. Importantly, RED-S should be considered not only as a condition that affects athletic performance but also as a syndrome that influences athletes' lifelong health and career continuity.

Although this systematic review provides a comprehensive overview of the effects of LEA and RED-S in elite female athletes, several limitations reflect those present in the existing literature. Most of the included studies were cross-sectional, which limits the ability to establish causal relationships between LEA and RED-S and subsequent performance or health outcomes. The limited number of prospective and randomized controlled trials also impacts the generalizability of the findings. Furthermore, small sample sizes and the inclusion of athletes from diverse sporting disciplines introduce variability, making it more difficult to interpret results given the physiological and metabolic differences between sports. The variety of methods used to assess LEA and RED-S risk (e.g., LEAF-Q, food diaries, RMR measurements, clinical symptom screening) limits comparability across studies and increases the potential for information bias, particularly when self-reported data are involved. Furthermore, the lack of longitudinal studies examining the long-term health effects of RED-S limits the ability to draw definitive conclusions about the syndrome's post-career and lifelong effects. Finally, the review's exclusive focus on female athletes excludes the effects of RED-S in male athletes and gender differences. These limitations highlight the need for more rigorous methodological designs and standardized measurement protocols in future research.

Current findings suggest the need to raise awareness of low energy intake (LEA) and relative energy deficiency in sport (RED-S) among elite female athletes. Future research should prioritize prospective and randomized controlled trials to better establish causal relationships. Additionally, increasing sample sizes and implementing standardized measurement protocols across sports will enhance the generalizability and comparability of study findings. Incorporating objective measurements, rather than relying solely on self-reported questionnaires, will reduce the information bias when assessing LEA and RED-S risk. Longitudinal follow-up studies and post-career data collection are also needed to understand the long-term health effects of RED-S. Furthermore, including male athletes in future research will allow a more comprehensive assessment of gender differences and risk profiles. Implementing these recommendations will advance scientific knowledge in sports medicine and performance management while enhancing the protection of athlete health.

CONFLICT OF INTERESTS

No potential conflict of interest was reported by the authors.

REFERENCES

1. Mountjoy, M., et al. (2018). IOC consensus statement on RED-S. *British Journal of Sports Medicine. https://doi.org/10.1123/ijsnem.2018-0136*.
2. Loucks, A. B. (2014). Energy availability in athletes. Journal of Sports Sciences, 29(sup1), S7–S15. https://doi.org/10.1080/02640414.2011.588958.
3. Melin, A., Tornberg, Å.-B., Skouby, S., Møller, S., Sundgot-Borgen, J., Faber, J., … (2019). Energy availability in athletics: Health, performance, and physique. International Journal of Sport Nutrition and Exercise Metabolism, 29(2), 152–164. https://doi.org/10.1123/ijsnem.2018-0270.
4. De Souza, M. J., Koltun, K. J., & Williams, N. I. (2014). The female athlete triad coalition consensus statement on treatment and return to play of the female athlete triad. British Journal of Sports Medicine, 48(4), 289–295. https://doi.org/10.1136/bjsports-2014-093575.
5. Mountjoy, M., et al. (2023). RED-S update. *British Journal of Sports Medicine.* https://doi.org/10.1136/bjsports-2023-106994.
6. Logue, D., et al. (2020). Low energy availability in athletes: Clinical consequences and assessment methods. Sports Medicine. https://pmc.ncbi.nlm.nih.gov/articles/PMC7146210/.
7. Kong, P., & Harris, L. M. (2013). The sporting body: Body image and eating disorder symptomatology among female athletes from leanness focused and non-leanness focused sports. The Journal of Psychology, 149(2), 141–160. https://doi.org/10.1080/00223980.2013.846291.
8. Tenforde, A. S., et al. (2017). Bone stress injuries in athletes. Current Sports Medicine Reports. https://doi.org/10.1016/j.pmr.2015.08.008.
9. Ackerman, K. E., Cano Sokoloff, N., De Nardo Maffazioli, G., Clarke, H. M., Lee, H., & Misra, M. (2015). Fractures in relation to menstrual status and bone parameters in young athletes. Medicine & Science in Sports & Exercise, 47(8), 1577–1586. https://doi.org/10.1249/MSS.0000000000000574.
10. Ackerman, K. E., & Misra, M. (2019). Effects of estrogen replacement on bone geometry and microarchitecture in oligo amenorrheic athletes. Journal of Bone and Mineral Research, 34(8), 1401–1409. https://doi.org/10.1002/jbmr.3887.
11. Klein, D. J., McClain, P., Montemorano, V., & Santacroce, A. (2023). Pre-season nutritional intake and prevalence of low energy availability in NCAA Division III collegiate swimmers.

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KOSALB International Journal of Human Movements Science, Vol: 4, No: 2, 2025, p 73-86, DOI: 10.70736/2958.8332.kosalb.65 | ISSN: 2958-8332 | Published: 27.12.2025
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Review Article

Nutrients, 15(13), 2827. https://doi.org/10.3390/nu15132827.
12. Ackerman, K. E., Stellingwerff, T., Elliott Sale, K. J., Baltzell, A., Cain, M., Goucher, K., … & Mountjoy, M. L. (2020). # REDS (Relative Energy Deficiency in Sport): Time for a revolution in sports culture and systems to improve athlete health and performance. British Journal of Sports Medicine, 54(7), 369–370. https://doi.org/10.1136/bjsports-2019-101140.
13. Pai, N. N., Brown, R. C., & Black, K. E. (2024). Risk of low energy availability and nutrition knowledge among female team sport athletes. *The Journal of sports medicine and physical fitness*, *64*(5), 446–454. https://doi.org/10.23736/S0022-4707.23.15273-X.
14. Rogers, M. A., Appaneal, R. N., Hughes, D., Vlahovich, N., Waddington, G., Burke, L. M., & Drew, M. (2021). Prevalence of impaired physiological function consistent with Relative Energy Deficiency in Sport (RED-S): An Australian elite and pre-elite cohort. *British Journal of Sports Medicine, 55*(1), 38–45. https://doi.org/10.1136/bjsports-2020-103428.
15. Meng, K., Qiu, J., Benardot, D., Carr, A., Yi, L., Wang, J., & Liang, Y. (2020). The risk of low energy availability in Chinese elite and recreational female aesthetic sports athletes. Journal of the International Society of Sports Nutrition, 17(1), 13. https://doi.org/10.1186/s12970-020-00346-0.
16. Miralles-Amorós, L., Asencio-Mas, N., Martínez-Olcina, M., Vicente-Martínez, M., Frutos, J. M. G. D., Peñaranda-Moraga, M., … & Martínez-Rodríguez, A. (2023).
17. Study the effect of relative energy deficiency on physiological and physical variables in professional women athletes: A randomized controlled trial. Metabolites, 13(2), 168. https://doi.org/10.3390/metabo13020168.
18. Kinoshita, N., Uchiyama, E., Ishikawa-Takata, K., Yamada, Y., & Okuyama, K. (2021). Association of energy availability with resting metabolic rates in competitive female teenage runners: A cross-sectional study. Journal of the International Society of Sports Nutrition, 18(1), 70. https://doi.org/10.1186/s12970-021-00461-0.
19. Scheid, J. L., Basile, S., & West, S. L. (2024). Low energy availability risk is associated with anxiety in female collegiate athletes. Sports, 12(10), 269. https://doi.org/10.3390/sports12100269.
20. Prus, D., Mijatovic, D., Hadzic, V., Ostojic, D., Versic, S., Zenic, N., … & Zaletel, P. (2022). (Low) energy availability and its association with injury occurrence in competitive dance: Cross-sectional analysis in female dancers. Medicina, 58(7), 853. https://doi.org/10.3390/medicina58070853.
21. Elliott, D. (2023). Energy availability and injuries in female football players. https://urn.fi/URN:NBN:fi:amk-2023060621836.
22. Kyte, K. H., Stensrud, T., Berg, T. J., Seljeflot, I., & Hisdal, J. (2022). Vascular function in Norwegian female elite runners: A cross-sectional, controlled study. Sports, 10(3), 37. https://doi.org/10.3390/sports10030037.

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*KOSALB International Journal of Human Movements Science, Vol: **4**, No: **2**, **2025**, p **73-86**, DOI: **10.70736/2958.8332.kosalb.65** | ISSN: **2958-8332** | Published: **27.12.2025***

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FOR CITATION

Akkuş Uçar M. The multidimensional impact of energy deficiency and low energy intake on elite female athletes: A systematic review. KOSALB Int J Hum Mov Sci. 2025;4(2):73–86. DOI: *10.70736/2958.8332.kosalb.65*.