A systematic review of risk factors, diagnostic criteria, and management strategies for the female athlete triad in endurance sports

Una revisión sistemática de los factores de riesgo, criterios de diagnóstico y estrategias de manejo para la tríada de la atleta femenina en deportes de resistencia

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Abstract

Background: The Female Athlete Triad and Relative Energy Deficiency in Sport (RED-S) remain significant health concerns that affect performance and long-term wellbeing in female athletes. Although individual components of the Triad are well studied, integrated evidence from recent research remains limited.
Objective: To systematically review and synthesize evidence from the most relevant observational studies examining the prevalence, risk factors, and physiological outcomes related to the Female Athlete Triad/RED-S.
Methods: A systematic review adhering to PRISMA 2020 guidelines was conducted using five databases (PubMed, Scopus, Embase, Web of Science, and Google Scholar). Studies from 2000 to 2024 were included if they focused on endurance athletes and addressed at least one component of the Triad. Ten empirical studies met the eligibility criteria. Data were extracted and narratively synthesized due to study heterogeneity.
Results: Most studies (7/10) demonstrated high methodological quality. Low energy availability was consistently associated with menstrual dysfunction and reduced bone mineral density, while validated screening tools such as the LEAF-Q showed strong applicability for early detection. Psychological factors, dietary behaviors, and training load were frequently implicated as risk modifiers. Despite heterogeneity in assessment methods, convergent evidence supports the multidimensional nature of Triad/RED-S risks. Limited longitudinal data and inconsistent diagnostic criteria were common limitations across studies.
Conclusion: The findings reinforce that low energy availability is a primary driver of Triad/RED-S manifestations and that early screening and multidisciplinary monitoring are critical for athlete health. Future research should focus on standardized diagnostic measures, longitudinal outcomes, and diverse athletic populations to strengthen evidence-based prevention strategies.

Keywords

Female athlete triad; low energy; bone mineral density; health; women.

Resumen

Antecedentes: La Tríada de la Atleta Femenina y la Deficiencia Energética Relativa en el Deporte (RED-S) siguen siendo problemas de salud importantes que afectan el rendimiento y el bienestar a largo plazo de las atletas. Si bien los componentes individuales de la Tríada están bien estudiados, la evidencia integrada de investigaciones recientes sigue siendo limitada.
Objetivo: Revisar y sintetizar sistemáticamente la evidencia de los estudios observacionales más relevantes que examinan la prevalencia, los factores de riesgo y los resultados fisiológicos relacionados con la Tríada de la Atleta Femenina/RED-S.
Métodos: Se realizó una revisión sistemática siguiendo las directrices PRIS-MA 2020 utilizando cinco bases de datos (PubMed, Scopus, Embase, Web of Science y Google Scholar). Se incluyeron los estudios realizados entre 2000 y 2024 si se centraban en atletas de resistencia y abordaban al menos un componente de la Tríada. Diez estudios empíricos cumplieron los criterios de elegibilidad. Se extrajeron los datos y se sintetizaron narrativamente debido a la heterogeneidad de los estudios. Resultados: La mayoría de los estudios (7/10) demostraron una alta calidad metodológica. La baja disponibilidad energética se asoció consistentemente con disfunción menstrual y reducción de la densidad mineral ósea, mientras que herramientas de cribado validadas como el LEAF-Q mostraron una gran aplicabilidad para la detección temprana. Factores psicológicos, hábitos alimentarios y carga de entrenamiento se implicaron frecuentemente como modificadores de riesgo. A pesar de la heterogeneidad en los métodos de evaluación, la evidencia convergente respalda la naturaleza multidimensional de los riesgos de la Tríada/RED-S. La escasez de datos longitudinales y la inconsistencia en los criterios de diagnóstico fueron limitaciones comunes en los estudios.
Conclusión: Los hallazgos refuerzan que la baja disponibilidad energética es un factor determinante principal de las manifestaciones de la Tríada/RED-S y que el cribado temprano y el seguimiento multidisciplinario son fundamentales para la salud de los atletas. La investigación futura debería centrarse en medidas diagnósticas estandarizadas, resultados longitudinales y poblaciones atléticas diversas para fortalecer las estrategias de prevención basadas en la evidencia.

Palabras clave

Tríada de la atleta femenina; baja energía; densidad mineral ósea; salud; mujeres.

Introduction

The participation of women in endurance sports has expanded considerably in recent decades, reflecting growing opportunities, improved training methodologies, and greater recognition of female athletes in competitive arenas. Alongside these advancements, however, health challenges unique to female athletes have gained increasing attention. Among these is the Female Athlete Triad (FAT). FAT is a multidimensional medical condition frequently observed in female endurance athletes, comprising three interrelated components: low energy availability (LEA), menstrual dysfunction, and low bone mineral density (BMD) (Mountjoy et al., 2014). These conditions, individually or collectively, pose a considerable threat to both the short-term performance and long-term health of athletes. In endurance sports, such as long-distance running, cycling, swimming, and triathlon, the prevalence of these issues is particularly high due to the intense training loads, body image pressures, and weight-sensitive performance demands that characterize these disciplines (Hutson et al., 2021). Endurance sports place unique physiological and psychological demands on female athletes. These athletes are often subject to substantial training loads and dietary restrictions, either due to intentional weight control or unintentional energy deficits, increasing the likelihood of LEA (Pienaar, 2023). LEA, defined as insufficient caloric intake relative to energy expended, acts as the primary initiator of the Triad cascade and can suppress reproductive and skeletal health (Angelidi et al., 2024). Evidence highlights that even short periods of energy deficiency can disrupt hormonal signaling pathways, leading to hypothalamic amenorrhea and compromised bone health (Cabre et al., 2022). Factors such as restrictive eating behaviors, intense training regimens, and sociocultural expectations surrounding leanness further amplify the risk (Beaudry et al., 2022; Warrick et al., 2023).

Menstrual dysfunction represents a key clinical manifestation of the Triad and serves as an early indicator of underlying energy imbalance. Prolonged menstrual disturbances are associated with suppressed estrogen levels, which negatively affect bone metabolism. A 2017 study in collegiate endurance athletes demonstrated that those experiencing ≥6 months of amenorrhea had approximately 30% lower lumbar spine BMD compared to eumenorrheic peers (Tenforde et al., 2017). These consequences are especially concerning in adolescent and young adult athletes, for whom peak bone mass acquisition is critical for long-term skeletal health. Such data underscore the importance of early detection and intervention to prevent cumulative skeletal damage during critical developmental years. The progression from LEA to menstrual dysfunction involves complex endocrine interactions. Hypothalamic-pituitary-gonadal axis suppression due to energy imbalance leads to decreased estrogen levels, which in turn impair ovulation and menstruation (Warrick et al., 2020). In adolescents and young adult women, this is particularly detrimental, as peak bone mass is typically achieved in late adolescence and early twenties. The absence of regular menses serves as a crucial early indicator of broader health dysfunction and should not be overlooked in clinical or sports medicine settings.

Relative energy deficiency syndrome in sports (RED-S) is one of the conditions that causes cardiovascular, metabolic, hematological, and psychological complications (Mountjoy et al., 2014). It also leads to endocrine dysfunction endocrine function resulting in menstrual irregularities and impaired bone health (Barrack et al., 2013). Although the International Olympic Committee (IOC) later introduced the concept of Relative Energy Deficiency in Sport (RED-S) to describe the broader multisystem consequences of LEA, the Female Athlete Triad remains a clinically relevant and widely used framework for understanding the specific interconnections between energy availability, reproductive function, and bone health in female athletes.Despite increasing research attention, important gaps remain in the literature regarding the FAT in endurance sports (Gibbs et al., 2014). Reported prevalence rates vary widely, reflecting heterogeneity in study designs, diagnostic criteria, and assessment methods (Casey, 2021). Moreover, the relative contribution of sport-specific risk factors, such as training volume, nutritional practices, and sociocultural pressures related to leanness, is not consistently defined. These limitations hinder effective screening, prevention, and management strategies for female endurance athletes.

Therefore, this systematic review aims to synthesize peer-reviewed literature on the prevalence, diagnostic criteria, associated risk factors, and management strategies of the Female Athlete Triad in endurance sports. By addressing these gaps, this review aims to support more consistent identification and management of the Triad within endurance sport settings and to inform future research and clinical

practice. It is structured according to the PICO framework: P (Population): Female endurance athletes, I (Exposure): Low energy availability; C (Comparison): Athletes with adequate energy availability, O (Outcome): Prevalence, diagnosis, and management outcomes. The review was conducted in accordance with the PRISMA 2020 guidelines, ensuring methodological transparency and comprehensive reporting to support future research and practical applications in sports medicine.

Method

Study Design

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. The review aimed to synthesize evidence on the prevalence, diagnostic criteria, risk factors, and management strategies related to the Female Athlete Triad (FAT) among endurance athletes.

Study Registration

This systematic review was conducted in accordance with PRISMA 2020 guidelines and followed an a priori protocol developed before study identification. Although the protocol was not registered in PROSPERO, it predefined the research question, eligibility criteria, search strategy, and data extraction plan. To minimize bias, study selection and data extraction were performed independently by two reviewers using predefined criteria, with disagreements resolved by consensus.

Eligibility Criteria

Studies were eligible for inclusion if they met the following criteria:

Population (P): Female endurance athletes of any competitive level (e.g., long-distance running, cycling, swimming, triathlon). Studies involving mixed athletic groups were included when endurance athlete data could be clearly identified or when the majority of the study sample comprised endurance disciplines.

Concept (I): At least one component of the Female Athlete Triad:

Low Energy Availability (LEA) or disordered eating; Menstrual dysfunction (e.g., amenorrhea, oligomenorrhea); Impaired bone mineral density (BMD).

Outcome (O): Prevalence, diagnostic criteria, associated risk factors, clinical consequences, or management/intervention strategies related to FAT.

Study Type: Peer-reviewed observational or interventional studies (cross-sectional, cohort, case-control, or trials).

Time Frame: Published between January 2000 and December 2024.

Language: Only articles published in English were included. This restriction was applied because the majority of research published in sports medicine is in English, and therefore only English-language research was considered.

Exclusion criteria included: male athletes, mixed-sport samples without separable endurance-specific data, reviews, theses, case reports, conference abstracts, and studies assessing conceptual overlap with Relative Energy Deficiency in Sport (RED-S) without explicitly addressing a FAT component.

Information Sources and Search Strategy

A comprehensive search was conducted in five electronic databases: PubMed, Scopus, Embase, Web of Science, and Google Scholar. Searches were run in May 2024. The search strategy used a broader OR-based Boolean structure, combining synonyms and MeSH terms, and keywords related to the Female Athlete Triad and endurance sports. The PubMed search strategy is presented below. Spelling variants (amenorrhoea/amenorrhea), keyword variations, and MeSH terms were included for completeness.

PubMed Search Strategy

("female athlete triad"[MeSH] OR "female athlete" OR "triad" OR "energy availability" OR "energy deficiency" OR "low energy availability" OR "disordered eating" OR "eating disorder"[MeSH] OR "menstrual dysfunction" OR "amenorrhea"[MeSH] OR "oligomenorrhea" OR "bone mineral density"[MeSH] OR "low BMD" OR "osteoporosis")

AND

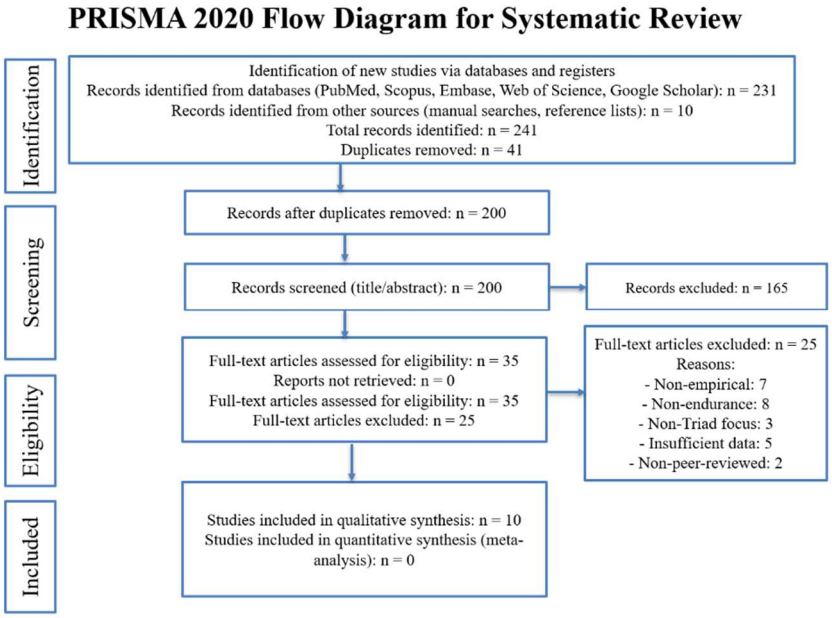
("endurance" OR "long-distance" OR "distance running" OR "marathon" OR "cycling" OR "swimming" OR "triathlon" OR "aerobic sports")

AND

("athlete*" OR "sportswomen" OR "female sports").

Figure 1 illustrates A PRISMA flowchart of the study identification, screening, eligibility assessment, and final inclusion process.

Figure 1: PRISMA Flow Diagram



Study Selection

Search results were imported into Zotero for systematic management. Duplicate entries were removed. Two reviewers independently screened titles and abstracts, followed by full-text screening using predefined criteria. Disagreements were resolved through consensus or third-reviewer adjudication.

A total of 231 records were initially identified. After removal of duplicates and sequential screening, 10 studies met the eligibility criteria and were included in the final synthesis. A detailed numerical breakdown for each exclusion step is presented in the PRISMA 2020 flow diagram.

Data Extraction

A standardized extraction form was used to collect: study characteristics (author, year, country, sample size), athlete characteristics (age, sport type, competitive level), diagnostic criteria used for FAT components, prevalence data, reported risk factors and clinical outcomes, and management or intervention strategies. Two reviewers independently extracted data to ensure accuracy.

Inter-rater Reliability

To assess the consistency of study selection between the two independent reviewers, inter-rater agreement was quantified using Cohen's kappa coefficient. The kappa value ($\kappa = 0.85$) was calculated based on a 2 × 2 concordance matrix comparing initial inclusion and exclusion decisions. Discrepancies were

resolved through discussion, and when consensus was not immediately reached, a third reviewer adjudicated. The detailed agreement matrix is provided in the Supplementary Materials.

Quality Assessment and Weighting in Narrative Synthesis

Study quality was evaluated using the Newcastle-Ottawa Scale (NOS) for observational studies and the Cochrane Risk of Bias Tool for randomized controlled trials (RCTs). Each study was classified as high, moderate, or low quality. Although no meta-analysis was performed, the narrative synthesis incorporated a structured weighting approach. Specifically, low-quality studies (n = 2) were not excluded outright but were given reduced interpretive influence by (i) prioritizing findings from high-quality studies when identifying patterns and concluding and (ii) explicitly identifying low-quality evidence when discussing inconsistent or uncertain findings. This qualitative down-weighting approach is consistent with established guidance for narrative evidence synthesis when statistical weighting is not applicable. NOS scores ≥7/9 were considered high quality, and RCTs were classified as low risk of bias when ≥5 of 7 Cochrane domains were rated as low risk. Table 2 shows a quality assessment summary

Data Synthesis

Given substantial heterogeneity across studies in athlete populations, endurance sport types, study designs, diagnostic definitions of Female Athlete Triad components, and reported outcomes, a narrative synthesis was undertaken. Heterogeneity was considered qualitatively high, particularly with respect to definitions and assessment methods for low energy availability, menstrual dysfunction, and bone mineral density. As no quantitative synthesis was conducted, I^2 statistics were not calculated.

Subgroup analyses by sport type were considered; however, these were limited by the small number of studies available within individual sport categories. Findings were therefore synthesized by grouping studies according to the following themes: (1) prevalence of Female Athlete Triad components, (2) associated risk factors, and (3) diagnostic and management strategies. Quantitative data were reported descriptively, including prevalence estimates, odds ratios (ORs), and corresponding confidence intervals (CIs). Meta-analysis was not performed due to heterogeneity in study designs, outcome measures, and diagnostic criteria, which precluded meaningful statistical pooling.

Ethical Considerations

This review is based exclusively on publicly available peer-reviewed studies and does not involve primary data collection involving human subjects. Therefore, ethical approval and informed consent were not required. All included studies were assumed to have obtained institutional ethical approval at the time of publication.

Results

This systematic review included 10 peer-reviewed empirical studies examining the Female Athlete Triad in female endurance athletes, encompassing adolescent, collegiate, and elite populations participating in sports such as distance running, triathlon, cycling, and swimming. Study designs included cross-sectional and prospective cohort methodologies (Table 1).

Low Energy Availability (LEA)

The reported prevalence of LEA varied substantially across studies, reflecting differences in assessment methods and diagnostic thresholds. Ackerman et al. (2016) reported LEA prevalence of 57% among competitive distance runners, whereas Beaudry et al. (2022) observed lower prevalence estimates (25–31%) in mixed endurance athlete samples using questionnaire-based assessments. Where reported, higher training volume was associated with increased likelihood of LEA (odds ratios ranging from 1.8 to 2.6 across studies), although confidence intervals varied and were not consistently reported.

Menstrual Dysfunction (MD)

MD prevalence ranged from 21% to 36% across included studies. Tenforde et al. (2017) reported that endurance athletes with prolonged training exposure had significantly higher odds of amenorrhea com-

pared with eumenorrheic peers (OR 2.3, 95% CI 1.4–3.9). Studies consistently reported higher MD prevalence among athletes with indicators of LEA, although heterogeneity in menstrual status definitions limited direct comparison.

Bone Mineral Density (BMD)

Low BMD prevalence ranged from 9% to 29% among endurance athletes, depending on age, sport, and DXA criteria used. In collegiate runners, Tenforde et al. (2017) reported significantly lower lumbar spine BMD Z-scores in athletes with ≥6 months of amenorrhea compared with eumenorrheic athletes (mean difference −0.6, $p < 0.01$). Several studies reported increased odds of bone stress injury among athletes presenting with multiple Triad components (OR range 2.0–3.1). Evidence from low-quality studies showed wider variability and was interpreted with caution.

Associated Risk Factors

Across studies, higher training volume, restrictive eating behaviors, lower body mass index, and reduced iron stores were consistently associated with increased prevalence of LEA and MD, as well as higher risk of adverse bone outcomes. Due to heterogeneity in exposure definitions and outcome measures, quantitative pooling of risk estimates was not performed.

Khan et al. (2002), the oldest study included, reported LEA, MD, and low BMD prevalence of 32%, 23%, and 17%, respectively. Due to its small sample size and pre-standardization methodology, these findings were interpreted with caution and considered lower-certainty evidence relative to more recent studies.

Overall, the interpretation of results was informed by methodological quality assessments. Findings consistently reported across studies rated as high or moderate quality were prioritized when describing prevalence patterns and associations, while results from low-quality studies were clearly identified and considered exploratory. Substantial heterogeneity in study populations, diagnostic definitions, and outcome reporting precluded meta-analysis. Therefore, results are presented as a structured narrative synthesis. Detailed study characteristics and key findings are summarized in Table 1.

Table 1. Characteristics and key findings of included studies (n = 10)

Study	Country	Design	Sample Size	Sport Type	Age (Mean ± SD)	LEA (%)	MD (%)	Low BMD (%)	Key Findings
Gibbs et al., 2013	USA	Cross-sectional	323	Runners, cyclists	20.5 ± 2.6	36 %	22%	15%	LEA most prevalent; a ≥ 2 components increased low BMD risk.
Tenforde et al., 2017	USA	Prospective	239	NCAA endurance athletes	19.7 ± 1.8	44%	30%	13%	Triad Risk Score a ≥ 5 predicted bone stress injury.
Torstveit & Sundgot-Borgen, 2005	Norway	Cross-sectional	669	Elite athletes (54% endurance)	21.4 ± 2.9	25%	24%	15%	Endurance athletes had 3Ã, higher MD risk.
Finn et al., 2021	USA	Cross-sectional	211	HS distance runners	17.2 ± 1.1	40%	21%	12%	Low ferritin correlated with LEA.
Ackerman et al., 2016	USA	Cross-sectional	79	Runners	20.8 ± 2.4	57%	36%	29%	Triad severity predicted BMD Z-scores.
Nose-Ogura et al., 2018	Japan	Survey	214	HS endurance athletes	16.9 ± 0.5	41%	35%	19%	MD associated with training >10h/week.
Segovia et al., 2020	USA	Survey	368	HS distance runners	17.1 ± 0.6	38%	28%	9%	Triad screen tool sensitivity = 89%.
Khan et al., 2002	Canada	Observational	74	Varsity runners	21.3 ± 2.8	32%	23%	17%	Osteopenia detected despite normal BMI.
Barrack et al., 2014	USA	Cross-sectional	170	Adolescent endurance athletes	16.5 ± 1.2	39%	32%	21%	LEA and MD strong predictors of low BMD; early screening recommended.
Reed et al., 2011	USA	Cross-sectional	240	Collegiate endurance athletes	19.3 ± 1.7	42%	29%	11%	MD significantly predicted reductions in lumbar spine BMD.

Table notes: LEA = low energy availability; MD = menstrual dysfunction; BMD = bone mineral density. Percentages reflect reported prevalence in each study sample using that study's methods/definitions.

Table 2. Quality Assessment Summary

Study	Design	Quality Tool	Score	Quality Rating	Key Notes
Gibbs et al. (2013)	Cross-sectional	NOS	8/9	High	Strong sampling strategy; clear diagnostic criteria; minimal bias.
Tenforde et al. (2017)	Prospective cohort	NOS	7/9	High	Well-designed cohort; minor loss to follow-up; robust outcome assessment.
Torstveit & Sundgot-Borgen (2005)	Cross-sectional	NOS	7/9	High	Large sample size; appropriate comparison group; sound methodology.
Finn et al. (2021)	Cross-sectional	NOS	6/9	Moderate	Reliance on self-reported LEA; potential recall bias.
Ackerman et al. (2016)	Cross-sectional	NOS	8/9	High	Use of validated tools (LEAF-Q, DXA); strong operational definitions.
Nose-Ogura et al. (2018)	Survey	NOS	6/9	Moderate	Small sample; self-report menstrual data; limited external validity.
Segovia et al. (2020)	Survey	NOS	7/9	High	Clear screening tool validation; good sensitivity and specificity analyses.
Khan et al. (2002)	Observational	NOS	5/9	Low	Small convenience sample; early diagnostic definitions; selection bias likely.
Barrack et al., 2014	Cross-sectional	NOS	7/9	High	Representative adolescent endurance sample; clear exposure/outcome measurement.
Reed et al. (2011)	Cross-sectional	NOS	7/9	High	Biochemical assessment of menstrual status; strong methodological clarity.

Discussion

This systematic review synthesized evidence from ten peer-reviewed studies examining the Female Athlete Triad (FAT) in female endurance athletes. Unless otherwise specified, interpretations in this section are derived exclusively from the ten included studies. References to broader frameworks, such as RED-S or the IOC consensus statements, are used only for contextual interpretation and are explicitly identified as such. Across adolescent, collegiate, and elite endurance-sport populations, the included studies reported elevated prevalence of low energy availability (LEA), menstrual dysfunction (MD), and low bone mineral density (BMD). However, substantial heterogeneity in study design, diagnostic criteria, and assessment methods limits direct comparability of prevalence estimates and necessitates cautious interpretation.

Prevalence and variability of Triad components

Across the included studies, prevalence estimates for LEA, MD, and low BMD varied widely due to differences in methods, populations, and diagnostic definitions. LEA prevalence ranged from approximately 25% to 57%, with lower estimates typically reported in larger multisport samples using brief screening tools (Torstveit & Sundgot-Borgen, 2005) and higher estimates observed in endurance-focused cohorts employing validated LEA questionnaires or detailed energy-availability assessments (Ackerman et al., 2016; Gibbs et al., 2013). This variability reflects substantial measurement heterogeneity, including differences in assessment instruments, cut-offs, and reporting thresholds. Prevalence also differed according to population characteristics such as age, training volume, and competitive level, which influence energy balance and menstrual physiology in endurance athletes (Tenforde et al., 2017).

Menstrual dysfunction prevalence ranged from 21% to 36% across studies, consistent with evidence from the included literature indicating that MD remains underrecognized and frequently normalized within endurance sport environments (Tenforde et al., 2017). Higher MD prevalence was reported among adolescent endurance athletes and those training more than 10 hours per week (Nose-Ogura et al., 2018). Low BMD was reported in 9% to 29% of athletes. Although less prevalent than LEA or MD, impaired bone density represents a clinically meaningful outcome because of its association with stress fractures, osteopenia, and long-term skeletal consequences (Tenforde et al., 2017). Variability in BMD prevalence was partly attributable to inconsistent diagnostic thresholds, differing DXA protocols, and variation in training history.

Methodological Factors Contributing to Heterogeneity

Several methodological factors across the included studies explain the observed heterogeneity. LEA assessment approaches ranged from self-report screening tools such as the LEAF-Q to indirect estimates based on dietary intake and training expenditure. Definitions of MD varied substantially, with some studies classifying dysfunction according to the number of missed menstrual cycles and others using

prolonged cycle length as the primary criterion. Similarly, BMD assessment lacked uniformity, with differing Z-score cut-offs and reference standards (Melin et al., 2014; Mountjoy et al., 2018). These inconsistencies limit direct comparison across studies and preclude quantitative synthesis.

Population characteristics further contributed to variability. Differences in age, competitive level, training load, and endurance discipline influenced reported prevalence patterns, with younger athletes and those competing at higher levels generally exhibiting greater Triad-related risk (Finn et al., 2021; Logue et al., 2018). The predominance of cross-sectional designs and the use of convenience sampling also limited causal inference and generalizability. Earlier studies with smaller sample sizes (e.g., Khan et al., 2002) were included for completeness but were interpretively down-weighted due to a higher risk of bias and reduced statistical precision.

Risk Factors and Interrelationships Among Triad Components

Within the ten included studies, LEA was frequently associated with MD and, in some cases, with impaired bone outcomes. Prospective and cohort studies provided stronger support for these associations than cross-sectional designs (Tenforde et al., 2017), although causal pathways could not be definitively established. While extensive external literature describes the LEA–MD–BMD pathway within the broader RED-S framework, conclusions in this review are based solely on patterns reported in the included studies and should therefore be interpreted as indicative rather than confirmatory.

Study Quality and Influence on Interpretation

Quality assessment indicated that most included studies were of moderate to high methodological quality, whereas a small number of early observational studies scored lower due to limitations such as small sample sizes and potential selection bias. These lower-quality studies were retained to provide historical context but did not drive overall conclusions. Instead, patterns consistently observed in studies rated as moderate to high quality were prioritized when interpreting prevalence trends and associations, in accordance with narrative synthesis principles.

Evidence-Based Implications for Endurance Athletes

Findings from the included studies suggest that female endurance athletes may benefit from systematic screening for LEA, as higher LEA prevalence was consistently reported in endurance-focused cohorts using validated assessment tools (Ackerman et al., 2016; Finn et al., 2021; Slater et al., 2017). Menstrual irregularities emerged as a common early indicator of underlying energy imbalance, with several studies reporting associations between MD, additional Triad components, and increased injury risk (Gibbs et al., 2013; Nose-Ogura et al., 2018; Reed et al., 2011). Additionally, endurance athletes presenting with multiple Triad components demonstrated higher risk of bone-related outcomes, including bone stress injury (Tenforde et al., 2017; Torstveit & Sundgot-Borgen, 2005). Although intervention evidence remains limited, the convergence of findings supports cautious consideration of multidisciplinary management approaches within endurance sport settings.

Strengths, Limitations, and Future Directions

This review followed PRISMA 2020 guidelines, applied structured quality assessment tools, and focused exclusively on endurance sports, enhancing conceptual precision. Nevertheless, limitations include the modest number of eligible studies, predominance of cross-sectional designs, lack of protocol registration, and substantial heterogeneity in diagnostic definitions and assessment tools. These methodological constraints directly limited the ability to perform meta-analysis and to draw causal conclusions. Although lower-quality studies were interpretively downweighted, no quantitative weighting is possible within a narrative synthesis framework.

Future research should prioritize prospective designs, standardized diagnostic criteria for all Triad components, and harmonized reporting of prevalence and risk estimates within endurance-specific populations. Addressing these gaps is essential to strengthen the evidence base and support more precise prevention, screening, and management strategies for female endurance athletes.

Conclusions

This systematic review synthesized evidence from ten observational studies investigating the prevalence, risk factors, and health implications of the Female Athlete Triad components in female endurance athletes. When interpreting the findings, greater weight was given to studies rated as moderate to high methodological quality based on the Newcastle–Ottawa Scale, while results from lower-quality studies were considered supportive but did not drive overall conclusions. Across the included studies, the evidence suggests that low energy availability represents a central and persistent factor associated with menstrual dysfunction and impaired bone health in female endurance athletes. Higher-quality studies consistently indicated associations between inadequate energy intake, high training load, and physiological disruption, whereas moderate-quality studies further highlighted the potential contribution of psychosocial and behavioral factors. Given the predominance of cross-sectional designs and methodological heterogeneity, these findings should be interpreted as indicative rather than causal. Despite variability in study methods and diagnostic definitions, the available evidence supports the cautious use of validated screening tools, such as the LEAF-Q, and the integration of nutritional, medical, and menstrual health monitoring within endurance sport settings. However, the strength of evidence remains limited, underscoring the need for careful clinical interpretation.

This review also identifies important gaps in the literature, including the limited number of longitudinal studies, inconsistent diagnostic thresholds, and underrepresentation of certain endurance disciplines and geographic regions. Addressing these limitations through standardized methodologies and prospective designs will improve risk stratification and support the development of more precise, evidence-informed prevention and management strategies.

References

Ackerman, K. E., Eguiguren, M. L., & Barrack, M. T. (2016). Risk Biotypes And The Female Athlete Triad. In Exercise and Human Reproduction (pp. 161–180). Springer. https://doi.org/10.1007/978-1-4939-3402-7_13

Angelidi, A. M., Stefanakis, K., Chou, S. H., & Mantzoros, C. S. (2024). Relative Energy Deficiency in Sport (REDs): Endocrine Manifestations, Pathophysiology and Treatments. Endocrine Reviews, 45(5), 676–703. https://doi.org/10.1210/endrev/bnae011

Barrack, M. T., Ackerman, K. E., & Gibbs, J. C. (2013). Update on the Female Athlete Triad. Current Reviews in Musculoskeletal Medicine, 6(2), 195-204. DOI: 10.1007/s12178-013-9168-9

Beaudry, A., Rizzone, K., Davis, S., Harvey, T., Gordon, P., & Chetlin, R. (2022). Female Athlete Triad Recognition and Knowledge of Collegiate Cross-Country Coaches. Journal of Women's Sports Medicine, 2(3), 112-124. https://doi.org/10.53646/jwsm.v2i2.31.

Cabre, H. E., Moore, S. R., & Smith-Ryan, A. E. (2022). Relative Energy Deficiency in Sport (RED-S): Scientific, Clinical, and Practical Implications for the Female Athlete. Deutsche Zeitschrift für Sportmedizin, 73(7), 308–316. https://doi.org/10.5960/dzsm.2022.546

Casey, E. K. (2021). The Female Athlete Triad/Relative Energy Deficiency in Sports. In The Female Athlete (pp. 295–310). Elsevier.

Finn, E. E., Tenforde, A. S., Fredericson, M., et al. (2021). Markers of Low Iron Status Are Associated With Female Athlete Triad Risk Factors. Medicine & Science in Sports & Exercise, 53(8), 1721–1728. https://doi.org/10.1249/MSS.0000000000002616

Gibbs, J. C., Williams, N. I., & De Souza, M. J. (2013). Prevalence Of Individual And Combined Components of the Female Athlete Triad. Medicine & Science in Sports & Exercise, 45(5), 985–996. https://doi.org/10.1249/MSS.0b013e31827f6a6b

Hutson, M. J., O'Donnell, E., Brooke-Wavell, K., Sale, C., & Blagrove, R. C. (2021). Effects of Low Energy Availability on Bone Health in Endurance Athletes and High-Impact Exercise as A Potential Countermeasure: A Narrative Review. Sports Medicine, 51(3), 391-403. https://doi.org/10.1007/s40279-020-01396-4

Khan, K. M., Liu-Ambrose, T., Sran, M. M., et al. (2002). New Criteria for Female Athlete Triad Syndrome? British Journal of Sports Medicine, 36(1), 10–13. https://doi.org/10.1136/bjsm.36.1.10

Logue, D., Madigan, S. M., Delahunt, E., Heinen, M., McDonnell, S. J., & Corish, C. A. (2018). Low Energy Availability in Athletes: A Review of Prevalence, Dietary Patterns, Physiological Health, and Sports Performance. Sports medicine, 48(1), 73-96.

Melin, A., Tornberg, Å. B., Skouby, S., Faber, J., Ritz, C., Sjödin, A., & Sundgot-Borgen, J. (2014). The LEAF questionnaire: A Screening Tool for the Identification of Female Athletes at Risk for the Female Athlete Triad. British journal of sports medicine, 48(7), 540-545.

Mountjoy, M., Sundgot-Borgen, J., Burke, L., et al. (2014). The IOC consensus statement: Beyond the Female Athlete Triad—Relative Energy Deficiency in Sport (RED-S). British Journal of Sports Medicine, 48(7), 491–497. https://doi.org/10.1136/bjsports-2014-093502

Nose-Ogura, S., Harada, M., Hiraike, O., et al. (2018). Management of the Female Athlete Triad. Journal of Obstetrics and Gynaecology Research, 44(12), 2129–2136. https://doi.org/10.1111/jog.13614

Pienaar, M. (2023). Nutritional Habits and the Relationship With RED-S Of Female Endurance Runners in Johannesburg [Master's dissertation, University of Witwatersrand]. https://wiredspace.wits.ac.za/handle/10539/34523

Reed, J. L., De Souza, M. J., & Williams, N. I. (2011). Bone Mineral Density and Menstrual Status in Collegiate Athletes. Journal of Clinical Endocrinology & Metabolism, 96(6), 1880–1887.

Segovia, N., Hastings, K., Skorseth, P., et al. (2020). Prevalence Of Female Athlete Triad Risk Factors and Iron Supplementation Among High School Distance Runners: Results from A Triad Risk Screening Tool. Orthopaedic Journal of Sports Medicine, 8(9), 1–9. https://doi.org/10.1177/2325967120959725

Slater, J., Brown, R., McLay-Cooke, R., & Black, K. (2017). Low Energy Availability in Exercising Women: Historical Perspectives and Future Directions. Sports Medicine, 47(2), 207-220. https://doi.org/10.1007/s40279-016-0583-0

Tenforde, A. S., Carlson, J. L., Chang, A., et al. (2017). Association of the Female Athlete Triad Risk Assessment Stratification with the Development Of Bone Stress Injuries in Collegiate Athletes. The American Journal of Sports Medicine, 45(6), 1540–1547. https://doi.org/10.1177/0363546516676262o

Torstveit, M. K., & Sundgot-Borgen, J. (2005). The Female Athlete Triad Exists in Both Elite Athletes and Controls. Medicine & Science in Sports & Exercise, 37(1), 144–153. https://doi.org/10.1249/01.MSS.0000150136.67225.1B

Warrick, A. E., Hassid, B., Coleman, B., Cansino, C., & Faustin, M. (2023). Multidisciplinary Physician Survey Assessing Knowledge of The Female Athlete Triad and Relative Energy Deficiency In Sport. Journal of Eating Disorders, 11(1), 70. https://doi.org/10.1186/s40337-023-00800-4

Warrick, A., Irish, J., & Morgenroth, D. (2020). The Female Athlete Triad: A Review of Current Literature. Current Reviews in Musculoskeletal Medicine, 13(4), 458–467. https://doi.org/10.1007/s12178-020-09645-8

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