Research Article

IJSEHR 2026; 10(1): 1-6

www.sportscienceresearch.com
Received: 18-02-2025
Accepted: 06-05-2026
Published: 30-06-2026
DOI: 10.31254/sportmed.10101

Energy Availability Throughout a Training Season in Division III Female Athletes: A Pilot Study

Tara K. Whiton[1], Jocelyn Skane[1], Zachary Adams[1], Madison Pelletier[1], Karen Croteau[1], Nina B. Eduljee[2]

[1] Department of Sport & Exercise Science, Saint Joseph's College of Maine, Standish, ME 04084, USA

[2] Department of Psychology, Saint Joseph's College of Maine, Standish, ME 04084, USA

Abstract

Background: NCAA Division III (DIII) athletes often lack dedicated nutrition resources, increasing their risk of Relative Energy Deficiency in Sport (RED-S). This pilot study investigated energy availability (EA) and nutritional status of NCAA DIII female athletes (n = 20) over a 6-week training period. **Methods:** Using a repeated-measures design, 20 female athletes (20 ± 1.1 years) across nine sports were assessed at three time points (DC1, DC2, and DC3). Data collection included laboratory assessments of body composition, resting metabolic rate, and the LEAF-Q screening tool; following each lab session, participants completed 7-day remote dietary tracking via the Cronometer app and maintained training logs to calculate energy expenditure. **Results:** High protocol adherence was observed (95.2%). The most significant finding was the pervasive nature of low energy availability (LEA); mean EA remained consistently below the clinical threshold of <30 kcal/kg FFM/day at all time points (23.7, 18.3, and 18.9 kcal/kg FFM/day, respectively). By DC3, 70% of participants were in clinical LEA and 0% achieved optimal EA. While 85% met physiological criteria for LEA, only 33% were identified as "at-risk" by the LEAF-Q. Dietary analysis revealed severe inadequacies in carbohydrate (2.3–2.5 g/kg/day) and protein (1.0–1.1 g/kg/day) relative to sport nutrition guidelines. **Conclusion:** DIII female athletes in our study faced a chronic "LEA load" driven by macronutrient deficits. Athletics departments should implement a universal screening tool that pairs the LEAF-Q with EA calculations to detect metabolic conservation, and should provide targeted education on fueling density.

Keywords: Energy expenditure; Fat-free mass (FFM); Nutritional assessment; Athletic performance; Dietary intake; Female athlete health.

***Corresponding author:**
Dr. Tara K. Whiton
Department of Sport & Exercise Science, Saint Joseph's College of Maine, Standish, ME 04084, USA
Email: twhiton@sjcme.edu

INTRODUCTION

Collegiate student-athletes navigate a demanding "dual-career" environment, balancing rigorous athletic performance with academic achievement. This unique pressure profile places them at heightened risk for Relative Energy Deficiency in Sport (RED-S). The syndrome of RED-S refers to impaired physiological functioning that is caused by relative energy deficiency and includes, but is not limited to, impairments in metabolic rate, menstrual function, bone health, immunity, protein synthesis, and cardiovascular health [1]. While RED-S can affect athletes of all genders, research consistently demonstrates a higher prevalence among females[2-7]. Within the collegiate landscape, NCAA Division III athletes represent the largest segment of the population yet receive the fewest nutrition-related resources, such as access to team-dedicated sports dietitians[8]. Consequently, DIII athletes are particularly vulnerable to insufficient nutritional intake and the development of Low Energy Availability (LEA)[9].

The underlying etiology of RED-S is LEA, a state where dietary energy intake is insufficient to support the physiological functions required for health and daily living after accounting for exercise energy expenditure [10-12]. Mathematically, Energy Availability (EA) is expressed as:

$$EA = \frac{(EI - EEE)}{FFM}$$

where EI - Energy Intake, EEE = Exercise Energy Expenditure and FFM = Fat Free Mass.

Standardized "zones of EA" categorize one's energy status into optimal (≥45 kcal/kg FFM/day), subclinical (30–45 kcal/kg FFM/day), and clinically low (< 30 kcal/kg FFM/day)[12]. While these thresholds provide a conceptual framework, individual sensitivity to LEA varies[13]. Chronic or acute LEA can trigger and impair multiple body systems responses, including metabolic rate, menstrual function, bone health and immune response, while simultaneously degrading strength and power[6,13,14].

Despite the clinical importance of EA, its assessment is notoriously challenging[15,16]. Accurate measurement requires high precision in tracking energy intake and expenditure, yet practitioners often rely on self-reported dietary methods prone to significant underreporting[17]. To mitigate these challenges, validated screening tools like the Low Energy Availability in Females Questionnaire (LEAFQ,[18] have been developed to identify risk based on physiological symptoms such as injury frequency and reproductive function[18,19]. Furthermore, the emergence of accessible mobile health (mHealth) applications (“apps”), such as Cronometer, offers a more robust means of monitoring food intake [20]. Cronometer has been shown to provide more comprehensive data on fiber and essential micronutrients compared to other market-leading apps[20]. Additionally, other research has shown that Cronometer was the only app with no significant differences in caloric or macronutrient estimates when compared to the Nutrition Data System for Research (NDSR) references for 3-day food records, making it the most accurate and powerful tool for longitudinal nutritional assessment[21].

These assessment tools are particularly critical during the preseason and competitive periods, when training volumes peak and physiological demands intensify[9]. To support such rigorous physical loads, carbohydrate requirements can surge to 7–12 g/kg/day, necessitating high-precision monitoring to ensure fueling adequacy[22,23]. Simultaneously, maintaining a protein intake of 1.2–2.0 g/kg/day and keeping dietary fat within 20–35% of total calories is essential for recovery and hormonal health[24], yet achieving this balance remains a significant challenge for the unguided athlete[25,26]. A synergistic blend of carbohydrates, proteins, fats, vitamins and minerals plays a pivotal role in enhancing sports performance while also maintaining a healthy body and it takes a concerted effort to achieve an appropriate balance that provides adequate energy in those with increased energy needs[22]. When these elevated requirements are combined with the logistical hurdles of student-athlete life, the risk of chronic LEA increases[27]. However, much of the existing literature relies on short-term, cross-sectional data, which fails to capture the cumulative "LEA load" an athlete may experience over time.

The purpose of this pilot study was three-fold:

- To assess the utility and athlete compliance of using remote tracking for physical activity and dietary intake in NCAA Division III female athletes across a full training season;
- To explore longitudinal EA tracking at multiple time points to capture the dynamic nature of energy balance; and
- To preliminarily examine macronutrient distribution relative to minimum sport nutrition recommendations (carbohydrates, protein, and fats).

By piloting the calculation of "LEA load" that accounts for both the magnitude and duration of energy deficits, this study moves beyond a "snapshot" in time to offer insight into the cumulative physiological effects of energy deficiency. As the first longitudinal assessment of its kind in the NCAA DIII female athlete population, this pilot work serves to establish a methodology and provide preliminary data for future large-scale investigations into energy deficiency.

MATERIALS AND METHODS

Subjects

The study began with n=21 female collegiate athletes. However, one athlete was excluded from the study due to incomplete data. The study was approved by the Institutional Review Board at the College and all subjects were told about the purpose of the study and completed an informed consent form. The subjects underwent three lab testing sessions and three separate weeks of data collection. To ensure data integrity, only subjects who completed all three laboratory sessions and associated dietary/activity logs were included.

Study Design

A prospective pilot study was conducted utilizing a repeated-measures design across a six-week training period during the spring academic semester. Data collection occurring at three time points (DC1, DC2, DC3) on an every-other-week schedule was specifically chosen to assess the feasibility of athlete engagement with intensive monitoring. Each session involved laboratory assessments of body composition, resting metabolic rate (RMR), and LEAF-Q Questionnaires, followed by seven continuous days of remote dietary and exercise tracking. This schedule allowed us to evaluate the logistical flow of our multi-method approach in a real-world collegiate setting.

Procedures:

Body Composition, RMR, and Questionnaires

Body composition was assessed via bioelectrical impedance analysis (BIA) using the Omron HBF-300 Body Fat Analyzer [28] to determine fat-free mass (FFM) and body fat percentage. Measurements were taken in a fasted state with participants standing upright, arms extended horizontally at a 90° angle to the torso, and hands firmly gripping the electrode handles. To ensure accuracy, the device was programmed with each participant’s height, weight, age, and sex. Total body fat percentage was used to derive FFM, which was recorded in kilograms (kg) for use in the Energy Availability (EA) equation.

RMR was measured via indirect calorimetry using the VO2 Master Pro (Version 1.1.1). The VO2 Master is a validated portable analyzer comparable to traditional metabolic carts [29]. Participants were tested in a fasted, rested state, having refrained from exercise and caffeine for at least 12 hours. The protocol consisted of a 5-minute "settle-in" period followed by a 5-minute measurement phase while seated. The device measured breath-by-breath ventilation and VO2 data were transmitted via Bluetooth to the mobile application for subsequent analysis.

Participants also completed the LEAF-Q [18] during each lab visit. This validated screening tool was used to assess physiological symptoms related to chronic LEA risk factors, specifically focusing on injury history, gastrointestinal function, and reproductive health [19]. A total score of ≥ 8 was utilized to identify athletes "at risk" for LEA and associated RED-S complications [19].

Remote Tracking

To capture real-world energy balance, the following tools were utilized during each 7-day data collection period (DC1, DC2, and DC3):

Dietary Intake: Nutritional data were captured as Energy Intake (EI) over seven continuous days using the Cronometer (2026, Version 4.48.6) mobile health (mHealth) application. Cronometer was selected for its extensive database and ability to track macronutrients [20]. Participants were instructed to log all food, beverages, and supplements. This allowed for the tracking of total caloric intake per day as well as precise macronutrient (g/day) (carbohydrates, protein, fat) distribution.

Energy Expenditure (Training Logs): To determine Exercise Energy Expenditure

(EEE), participants maintained detailed daily training logs for seven continuous days (DC1, DC2, DC3). Athletes recorded the specific type, duration, and perceived intensity of all training sessions and competitive events. These logs were then cross-referenced with standard Metabolic Equivalents of Task (MET) [30] values to calculate daily activity-related energy expenditure (kcal/day).

Energy Availability (EA) Calculation

Energy Availability was calculated for each participant as the daily average across each seven-day collection period (DC1, DC2, DC3) using the formula:

$$EA = \frac{(EI - EEE)}{FFM}$$

where EI - Energy Intake, EEE = Exercise Energy Expenditure and FFM = Fat Free Mass.

Statistical Analysis

Descriptive statistics (mean ± SD) were calculated for anthropometrics, body composition, and nutritional parameters (EA, EI, EEE, and macronutrient distribution). A one-way repeated measures Analysis of Variance (ANOVA) was used to compare changes in EA and RMR across the three time points. All statistical analyses were performed using SPSS v.28, with significance set at $p < 0.05$.

RESULTS

Subject Characteristics, Anthropometrics and Body Composition

Participant characteristics (mean ± SD) were: 20 ± 1.1 years of age, 164.3 ± 5.5 cm in height. The cohort represented nine different athletic programs: indoor track and field n=1, outdoor track and field n=2, alpine ski n=1, golf n=2, field hockey n=2, softball n=1, volleyball n=2, lacrosse n=2, and soccer n=7. Regarding protocol feasibility, participant retention was high, with 95.2% (n=20) of the initial cohort completing all three data collection points. Athletes demonstrated a strong adherence to the remote tracking requirements providing an average of 4.9 ± 1.6, 6.2 ± 1.3, and 5.1 ± 1.5 days of logged activity data for collection windows DC1, DC2, and DC3, respectively, reflecting assigned training programs as assigned by coaches. Dietary tracking was similarly robust, with participants recording data for all 7 days for each collection window. In instances of missing dietary data, researchers facilitated dietary recall sessions to ensure completeness.

Baseline physical characteristics for the sample are presented in Table 1. There were no significant changes in body mass (p = 0.99), body fat percentage (p = 0.99), or lean body mass (LBM) (p = 0.95) across the three data collection periods (DC1, DC2, DC3).

Table 1: Body Composition Characteristics (Mean ± SD)

Body Composition	DC1 Mean ± (SD)	DC2 Mean ± (SD)	DC3 Mean ± (SD)	*p* value
Body Mass (kg)	71.1 (11.7)	70.6 (11.5)	71.0 (11.7)	0.99
Body Fat (%)	25.8 (5.6)	26.2 (5.5)	25.7(5.3)	0.99
FFM (kg)	52.4 (5.1)	52.5 (4.6)	52.4 (5.2)	0.95

Prevalence of Low Energy Availability (LEA) Risk

The distribution of EA categories remained skewed toward clinical risk throughout the study. At the final assessment, 70% (n=14) of participants were classified as having "Clinical LEA" (<30 kcal/kg FFM/day), while 30% (n=6) fell within the "Reduced EA" range (30–45 kcal/kg FFM/day). Notably, 0% (n=0) of the athletes achieved "Optimal EA" (≥45 kcal/kg FFM/day) at any point during the training season (Table 2).

Table 2: Distribution of Participants Across Energy Availability Categories

	DC1	DC2	DC3
	Frequency		
Low EA associated with health implications (<30 kcal/kg FFM/day)	16	17	17
Reduced EA for body mass/fat loss (30-45 kcal/kg FFM/day)	4	3	3
Adequate EA for weight maintenance and support of body function (~45 kcal/kg FFM/day)	0	0	0
High EA for mass gain and growth (≥45 kcal/kg FFM/day)	0	0	0

LEAF-Q Results

Parallel to the physiological findings, the Low Energy Availability in Females Questionnaire (LEAF-Q) results indicated a consistent subset of athletes at high risk for clinical consequences. Throughout the study, the average total score remained relatively stable, transitioning from 6.2 ± 3.7 at the initial assessment to 5.6 ± 3.8 by the final lab session. This slight decrease in total score in the final lab session is attributable to a subject dropping out of the study. Despite these modest averages, approximately 33% (n=7) of the cohort consistently met or exceeded the clinical threshold score of ≥8, classifying them as "at risk" for LEA (Table 3). The results of the *t*-test indicated significant differences were obtained between weeks and LEAF-Q scores (p < 0.01).

Table 3: LEAF-Q Scores and Prevalence of Risk

Metric	DC1 Mean ± (SD)	DC2 Mean ± (SD)	DC3 Mean ± (SD)	*p* value
Mean	6.2 (3.7)	6.0 (4.0)	5.6 (3.8)	<0.01**
N at risk	7	7	6	
N not at risk	14	14	14	
N total	21	21	20	
Prevalence of risk	33%	33%	33%	

Energy Availability (EA)

Mean EA for the cohort was consistently below the clinical threshold of 30 kcal/kg FFM/day at all three time points. Mean EA was 23.7 ± 8.9 kcal/kg FFM/day (range: 2.8 – 37.4) at Data Collection (DC) 1, 18.3 ± 10.7 kcal/kg FFM/day (range: -1.0 – 32.5) at DC2, and 18.9 ± 14.2 kcal/kg FFM/day (range: -3.4 – 35.5) at DC3 (Table 4). Repeated-measures ANOVA revealed a statistically significant main effect of time on Energy Availability (p <0.01). In contrast, a separate repeated-measures ANOVA for dietary fat percentage demonstrated no statistically significant differences across time points (p=0.315).

Macronutrient Intake Parameters

Dietary intake parameters remained stable across the training period, with no statistically significant week-to-week differences observed for total energy intake (p=0.014), carbohydrates (p=0.478), protein (p=0.238), or fat (p=0.315).

When compared to sport-specific recommendations, the cohort demonstrated consistent inadequacies for daily carbohydrate and protein intake. Mean daily carbohydrate intake was lower than the recommended 5–12 g/kg/day for high-intensity and endurance athletes at all time points. Mean daily protein intake fell below the recommended 1.2–2.0 g/kg/day across the study duration. Mean daily fat intake fell within the recommended range of 20–35% of total daily calories at all time points (Table 5).

Table 4: Energy Balance Parameters (Mean ± SD)

	DC1 Mean ± (SD)	DC2 Mean ± (SD)	DC3 Mean ± (SD)	*p* value
Carbohydrate (g/kg)	2.5 (0.9)	2.3 (0.8)	2.3 (1.0)	0.25
Fat (% total daily calories)	27.5 (0.2)	29.7 (0.2)	29.3 (0.2)	0.315
Protein (g/kg)	1.1 (0.3)	1.0 (0.4)	1 (0.3)	0.238
RMR (kcal/day)	1950.6 (455.1)	2075.6 (313.2)	2134.9 (360.8)	0.33
Activity EE (kcal/day)	366.5 (360.1)	451.1 (361.5)	478.3 (411.4)	N/A
Energy Availability (kcal/kg/FFM)	24.5 (12.5)	18.3 (13.1)	18.9 (14.2)	< 0.001

Table 5: Comparison of Observed Macronutrient Intake and Energy Availability Against International Sports Nutrition Guidelines

Nutrient	Current Study Mean ± (SD)	Recommended Range	Compliance Status
Carbohydrates	2.3±0.9 g/kg/day	5.0–12.0 g/kg/day	Severe Inadequacy
Protein	1.0±0.3 g/kg/day	1.2–2.0 g/kg/day	Inadequate
Dietary Fat	28.8±0.2 % total kcal	20–35 % total kcal	Adequate
Energy Availability	20.5±13.2 kcal/kg FFM/day	≥45 kcal/kg FFM/day	Clinical Risk (<30)

DISCUSSION

The primary objective of this study was to evaluate the longitudinal energy availability and nutritional status of NCAA Division III female athletes during a training season. Much of the prior research in this area focuses on a single snapshot of EA in athletes. The most significant finding was the pervasive and chronic nature of Low Energy Availability (LEA) within this cohort. Throughout the six-week study, 80–85% of athletes consistently fell below the clinical threshold for LEA (<30 kcal/kg FFM/day) despite having athletes of different sports in different training seasons. Research indicates that the prevalence of LEA in female athletes involved in various sports is wide ranging from as low as 12% to 100% [4,9,31-34]. Notably, not a single participant in the present study achieved "optimal" energy availability (≥45 kcal/kg FFM/day) at any time point. These results highlight a severe, systemic deficit in energy intake relative to training demands and regardless of sport in our studied population. Other research findings have also suggested that "optimal" energy availability is rarely attained in competitive sporting environments often due to high training volumes and intention or unintentional undereating[35-38].

Prevalence and LEA Load

While cross-sectional studies often capture a single moment of deficiency, the results from this pilot study suggest that for our sample of DIII female athletes, LEA is a stable state rather than a transient fluctuation. The mean EA values across DC1, DC2, and DC3 (24.5, 18.3, and 18.9 kcal/kg FFM/day, respectively) indicate a cohort in a state of chronic energy conservation. The "LEA load", or the cumulative effect of remaining in a deficit, is evidenced by the fact that 16 out of 20 athletes began the season in a clinical deficit, and this number increased to 17 by the end of the study. This suggests that as the training season progressed and EEE increased (from 366.5 to 478.3 kcal/day), athletes failed to adjust their EI to compensate, leading to even lower EA values. It is not uncommon to observe this trend in athletic populations where EA deteriorates as training demands increase throughout a season[1,37].

Interestingly, while 85% of the cohort met the physiological criteria for LEA (<30 kcal/kg FFM/day), only 33% (n=7) were classified as 'at risk' by the LEAF-Q (≥8). This discrepancy suggests a significant portion of the cohort may be in a 'subclinical' phase of RED-S. Other research has discussed the shortfalls of the LEAF-Q in that it may miss athletes who are in adaptable or early-stage LEA and have not yet developed symptoms of LEA[39,40]. In adaptable or early-stage LEA, metabolic conservation is occurring as evidenced by the stable body mass and suppressed RMR, but has not yet progressed to the point of menstrual dysfunction or frequent injury as captured by the LEAF-Q[1, 39,40]. This highlights the danger of relying solely on symptom-based screening. Athletes may be physiologically compromised long before they fail a subjective questionnaire.

Macronutrient Inadequacies as a Driver of LEA

The underlying cause of the observed LEA appears to be a failure to meet fundamental sport nutrition requirements, specifically for carbohydrates and protein. Current guidelines for carbohydrates recommend 5–12 g/kg/day for athletes in training[22,23], but the current cohort averaged only 2.3–2.5 g/kg/day, similar to other research that has reported low daily carbohydrate intakes in training athletes[41-44]. Such low intakes of carbohydrate when matched for training demand represents a critical fueling gap that not only drives LEA but also impairs glycogen resynthesis, high-intensity performance capacity, and recovery from training[45-47].

In the present study, participants averaged 1.0–1.1 g/kg/day of protein, consistently falling below the recommended 1.2–2.0 g/kg/day [25]. Insufficient protein during high-volume training blocks can compromise muscle repair and lead to a negative nitrogen balance, further exacerbating the physiological stress of RED-S [48,49].

Interestingly, fat intake remained within the recommended 20–35% range. This suggests that athletes may be consuming enough fat for general health but are failing to prioritize the carbohydrate and protein sources necessary for glycogen resynthesis and muscle recovery. Despite meeting the recommendations for one macronutrient group, overall deficiencies in energy still have negative consequences on an athlete's performance including losses of fat free mass, disturbances in immune function, decreased bone mineral density, and increased susceptibility to injury and overtraining [43].

The lack of change in body mass despite chronic LEA is a hallmark of metabolic adaptation [50]. In states of chronic energy deficiency, the body suppresses non-essential physiological functions (e.g., reproductive function, bone turnover) to maintain weight on fewer calories [12]. This is supported by our finding that RMR was actually measured to be lower than EI in some instances, indicating a potentially suppressed metabolic rate.

NCAA Division III Resource Gaps

These findings underscore the vulnerability of the Division III student-athlete. Unlike Division I programs, which often employ full-time sports dietitians and provide training tables, DIII athletes are largely responsible for their own nutritional management [8]. The combination of high training volumes, academic rigor, and limited professional nutritional guidance can contribute to the high prevalence of "unintentional LEA" [51-52].

Clinical and Practical Implications

The use of mHealth tools like Cronometer provided a feasible and accessible method for these athletes to track their intake, and preliminary findings suggest a significant pattern of under-fueling. For athletic departments at the DIII level, these results suggest that:

- The high completion rate of the LEAF-Q in this study suggests that it was a useful screening tool for DIII athletes, however, it may under-detect LEA risk.

- Pilot data in the present study suggests that educational interventions should focus specifically on increasing carbohydrate and protein density to match fluctuating training loads.
- Our results highlight that the utility of monitoring "LEA Load" is more valuable than single-point assessments, as the cumulative deficit likely poses the greatest risk to long-term bone and reproductive health.

Our pilot work supports the recommendation that universal screening should pair the LEAF-Q with energy availability (EA) calculations or RMR testing where possible to capture 'silent' LEA before it progresses to clinical RED-S.

Limitations and Future Recommendations

As a pilot study, this research was designed to assess the feasibility of the protocol within a competitive collegiate setting. While the small sample size (n=20) and sport-specific subgroups limit the generalizability of the findings to broader populations, they provide preliminary data necessary for power calculations in future large-scale studies. The reliance on self-report logs and MET-based EEE calculations may be subject to the "observer effect" and inadequate consideration for individual metabolic variation, however, these methods served to evaluate the practicality and athlete compliance of non-invasive monitoring. Such methods are often preferred by coaching staff and athletes to minimize disruption of the training process [53]. These pilot results suggest that while the framework is viable, future studies with larger gender-diverse sample sizes should incorporate more precise physiological measurements to build upon these initial observations. Additionally, a universal screening tool should be implemented in Athletics Departments to determine specifically which groups may be at risk for such nutritional deficits so targeted nutritional education programs can be implemented.

CONCLUSION

The results of this pilot study indicate that Female NCAA Division III athletes are at extreme risk for LEA and the subsequent complications of RED-S. The consistent failure to meet carbohydrate and protein recommendations suggests that current nutritional strategies in this population are insufficient to support the demands of collegiate sport. Future research should investigate the long-term health outcomes of this "LEA load" and the efficacy of low-cost, app-based nutritional interventions in the DIII setting.

Author Contributions

TW conceptualized, designed, and supervised the study. TW, JS, ZA, MP did the literature search and conducted the experiment. Manuscript preparation was done by TW, KC, and NE. Data acquisition was done by TW. Statistical analysis was performed by NE. Manuscript editing was done by TW, KC, and NE. All authors reviewed and approved the final version of the manuscript.

Data Availability Statement

The data that support the findings of this study are available and will be made available upon request.

Use of AI in Drafting of Manuscript

The authors declare that they have not used any generative AI/AI-assisted technologies in the writing of this manuscript.

Conflicts of Interest

The authors declared no conflict of interest.

Financial Support

None declared.

ORCID ID

Tara K. Whiton: https://orcid.org/0009-0007-0795-6493

Jocelyn Skane: https://orcid.org/0009-0006-8583-630X

Zachary Adams: https://orcid.org/0009-0002-8945-8052

Madison Pelletier: https://orcid.org/0009-0003-1705-2085

Karen Croteau: https://orcid.org/0000-0002-6980-5582

Nina B. Eduljee: https://orcid.org/0009-0005-2283-6102

REFERENCES

1. Mountjoy M, Ackerman KE, Bailey DM, Burke LM, Constantini N, Hackney AC, *et al.* IOC consensus statement on Relative Energy Deficiency in Sport (REDs). Br J Sports Med. 2023;57(17):1073-98.
2. Beals KA. Eating behaviors, nutritional status, and menstrual function in elite female adolescent volleyball players. J Am Diet Assoc. 2002;102(9):1293-6.
3. Jagim AR. The influence of sport nutrition knowledge on body composition and perceptions of dietary requirements in collegiate athletes. Nutrients. 2021;13(7):2239.
4. Magee MK, Lockard BL, Zabriskie HA, Schaefer AQ, Luedke JA, Erickson JL, *et al.* Prevalence of low energy availability in collegiate women soccer athletes. J Funct Morphol Kinesiol. 2020;5(4):96.
5. Marzuki MIH, Mohamad MI, Chai WJ, Farah NMF, Safii NS, Jasme JK, *et al.* Prevalence of Relative Energy Deficiency in Sport (RED-S) among national athletes in Malaysia. Nutrients. 2023;15(7):1697.
6. Mountjoy M, Sundgot-Borgen J, Burke L, Carter S, Constantini N, Lebrun C, *et al.* The IOC consensus statement: beyond the Female Athlete Triad--Relative Energy Deficiency in Sport (RED-S). Br J Sports Med. 2014;48(7):491-7.
7. Valliant MW, Pittman Emplaincourt H, Kieckhaefer Wenzel R, Garner BH. Nutrition education by a registered dietitian improves dietary intake and nutrition knowledge of a NCAA female volleyball team. Nutrients. 2012;4(6):506-16.
8. NCAA. Our Division III members [Internet]. NCAA.org; [cited 2025 Nov 4]. Available from: https://www.ncaa.org/sports/2021/5/11/our-division-iii-members.aspx
9. Klein DJ, McClain P, Montemorano V, Santacroce A. Pre-season nutritional intake and prevalence of low energy availability in NCAA Division III collegiate swimmers. Nutrients. 2023;15(13):2827.
10. Cabre H, Moore S, Smith-Ryan A, Hackney A. Relative Energy Deficiency in Sport (RED-S): scientific, clinical, and practical implications for the female athlete. Dtsch Z Sportmed. 2022;73(7):225-34.
11. Chesters RL, Soundy A, Wallis GA. Voluntary and involuntary risk of low energy availability (LEA): a narrative synthesis review of screening tools for athletes. Perform Nutr. 2025;1(1):9.
12. Loucks AB, Kiens B, Wright HH. Energy availability in athletes. J Sports Sci. 2011;29 Suppl 1:S7-15.
13. Areta JL. Physical performance during energy deficiency in humans: an evolutionary perspective. Comp Biochem Physiol A Mol Integr Physiol. 2023;284:111473.
14. Logue DM, Madigan SM, Melin A, Delahunt E, Heinen M, Donnell SJM, *et al.* Low energy availability in athletes 2020: an updated narrative review of prevalence, risk, within-day energy balance, knowledge, and impact on sports performance. Nutrients. 2020;12(3):835.
15. Burke LM, Lundy B, Fahrenholtz IL, Melin AK. Pitfalls of conducting and interpreting estimates of energy availability in free-living athletes. Int J Sport Nutr Exerc Metab. 2018;28(4):350-63.
16. Tarnowski CA, Wardle SL, O'Leary TJ, Gifford RM, Greeves JP, Wallis GA. Measurement of energy intake using the principle of energy balance overcomes a critical limitation in the assessment of energy availability. Sports Med Open. 2023;9(16):1-7.
17. Capling L, Beck KL, Gifford JA, Slater G, Flood VM, O'Connor H. Validity of dietary assessment in athletes: a systematic review. Nutrients. 2017;9(12):1313.

18. Melin A. Low Energy Availability in Females Questionnaire (LEAF-Q). DiVA Portal; 2013.
19. Melin A, Tornberg AB, Skouby S, Faber J, Ritz C, Sjödin A, *et al*. The LEAF questionnaire: a screening tool for the identification of female athletes at risk for the female athlete triad. Br J Sports Med. 2014;48(7):540-5.
20. Li X, Yin A, Choi HY, Chan V, Allman-Farinelli M, Chen J. Evaluating the quality and comparative validity of manual food logging and artificial intelligence-enabled food image recognition in apps for nutrition care. Nutrients. 2024;16(15):2573.
21. Gioia S, Vlasac IM, Babazadeh D, Fryou NL, Do E, Love J, *et al*. Mobile apps for dietary and food timing assessment: evaluation for use in clinical research. JMIR Form Res. 2023;7:e35858.
22. Amawi A, AlKasasbeh W, Jaradat M, Almasri A, Alobaidi S, Hammad AA, *et al.* Athletes' nutritional demands: a narrative review of nutritional requirements. Front Nutr. 2024 Jan 18;10. Available from: https://www.frontiersin.org/journals/nutrition/articles/10.3389/fnut.2023.1331854/full
23. Burke LM, Cox GR, Cummings NK, Desbrow B. Guidelines for daily carbohydrate intake. Sports Med. 2001;31(4):267-99.
24. Liu AG, Ford NA, Hu FB, Zelman KM, Mozaffarian D, Kris-Etherton PM. A healthy approach to dietary fats: understanding the science and taking action to reduce consumer confusion. Nutr J. 2017;16:53;1-15.
25. Jäger R, Kerksick CM, Campbell BI, Cribb PJ, Wells SD, Skwiat TM, *et al*. International Society of Sports Nutrition position stand: protein and exercise. J Int Soc Sports Nutr. 2017;14:20.
26. Tipton KD, Witard OC. Protein requirements and recommendations for athletes: relevance of ivory tower arguments for practical recommendations. Clin Sports Med. 2007;26(1):17-36.
27. Thomas DT, Erdman KA, Burke LM. Nutrition and athletic performance. Med Sci Sports Exerc. 2016;48(3):543-68.
28. Martín Moreno V, Gómez Gandoy B, Antoranz González M, Fernández Herranz S, Gómez De La Cámara A, de Oya Otero M. Validation of the OMRON BF 300 monitor for measuring body fat by bioelectric impedance. Aten Primaria. 2001;28(3):174-81.
29. Montoye AHK, Vondrasek JD, Hancock JB. Validity and reliability of the VO2 Master Pro for oxygen consumption and ventilation assessment. Int J Exerc Sci. 2020;13(4):1382-1401.
30. Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR, Tudor-Locke C, *et al*. 2011 compendium of physical activities: a second update of codes and MET values. Med Sci Sports Exerc. 2011;43(8):1575-81.
31. Logue D, Madigan SM, Delahunt E, Heinen M, Mc Donnell SJ, Corish CA. Low energy availability in athletes: a review of prevalence, dietary patterns, physiological health, and sports performance. Sports Med. 2018;48(1):73-96.
32. Logue DM, Madigan SM, Melin A, Delahunt E, Heinen M, Donnell SJM, *et al*. Low energy availability in athletes 2020: an updated narrative review of prevalence, risk, within-day energy balance, knowledge, and impact on sports performance. Nutrients. 2020;12(3):835.
33. Torres-McGehee TM, Emerson DM, Pritchett K, Moore EM, Smith AB, Uriegas NA. Energy availability with or without eating disorder risk in collegiate female athletes and performing artists. J Athl Train. 2021;56(9):993-1002.
34. Willingham BD, Daou M, VanArsdale J, Thomas M, Saracino PG. Energy availability in female collegiate beach volleyball athletes. J Strength Cond Res. 2024;38(11):1941-50.
35. Dave SC, Fisher M. Relative energy deficiency in sport (RED-S). Curr Probl Pediatr Adolesc Health Care. 2022;52(8):101242.
36. Melin AK, Heikura IA, Tenforde A, Mountjoy M. Energy availability in athletics: health, performance, and physique. Int J Sport Nutr Exerc Metab. 2019;29(2):152-164.
37. Melin AK, Areta JL, Heikura IA, Stellingwerff T, Torstveit MK, Hackney AC. Direct and indirect impact of low energy availability on sports performance. Scand J Med Sci Sports. 2024;34(1):e14327.
38. Torres-McGehee TM, Emerson DM, Pritchett K, Moore EM, Smith AB, Uriegas NA. Energy availability with or without eating disorder risk in collegiate female athletes and performing artists. J Athl Train. 2021;56(9):993-1002.
39. Dasa MS, Friborg O, Kristoffersen M, Pettersen G, Sagen JV, Sundgot-Borgen J, *et al*. Evaluating the suitability of the Low Energy Availability in Females Questionnaire (LEAF-Q) for female football players. Sports Med Open. 2023;9:54.
40. Rogers MA, Drew MK, Appaneal R, Lovell G, Lundy B, Hughes D, *et al*. The utility of the Low Energy Availability in Females Questionnaire to detect markers consistent with low energy availability-related conditions in a mixed-sport cohort. Int J Sport Nutr Exerc Metab. 2021;31(5):427-37.
41. Holway FE, Spriet LL. Sport-specific nutrition: practical strategies for team sports. J Sports Sci. 2011;29 Suppl 1:S115-25.
42. Jenner SL, Trakman G, Coutts A, Kempton T, Ryan S, Forsyth A, *et al*. Dietary intake of professional Australian football athletes surrounding body composition assessment. J Int Soc Sports Nutr. 2018;15(1):43.
43. Jenner SL, Devlin BL, Forsyth AK, Belski R. Dietary intakes of professional Australian football league women's (AFLW) athletes during a preseason training week. J Sci Med Sport. 2019;22(11):1266-71.
44. Otte CJ, Mantzioris E, Salagaras BS, Hill AM. Comparison of Australian Football League Women's athletes match day energy and nutrient intake to recommendations. Nutr Diet. 2024;81(3):325-34.
45. Henselmans M, Bjørnsen T, Hedderman R, Vårvik FT. The effect of carbohydrate intake on strength and resistance training performance: a systematic review. Nutrients. 2022;14(4):856.
46. Kerksick CM, Wilborn CD, Roberts MD, Smith-Ryan A, Kleiner SM, Jäger R, *et al*. ISSN exercise & sports nutrition review update: research & recommendations. J Int Soc Sports Nutr. 2018;15(1):38.
47. Naderi A, Rothschild JA, Santos HO, Hamidvand A, Koozehchian MS, Ghazzagh A*, et al*. Nutritional strategies to improve post-exercise recovery and subsequent exercise performance: a narrative review. Sports Med. 2025;55(7):1559-77.
48. Jahan-Mihan A, El Khoury D, Brewer GJ, Chapleau A. Current perspectives on protein supplementation in athletes: general guidance and special considerations for diabetes-a narrative review. Nutrients. 2025;17(22):3528.
49. Oxfeldt M, Phillips SM, Andersen OE, Johansen FT, Bangshaab M, Risikesan J, *et al*. Low energy availability reduces myofibrillar and sarcoplasmic muscle protein synthesis in trained females. J Physiol. 2023;601(16):3481-97.
50. Suzuki D, Suzuki Y. Identifying and analyzing low energy availability in athletes: the role of biomarkers and red blood cell turnover. Nutrients. 2024;16(14):2273.
51. Burger S, Bray A, Kim B. The relationship between nutrition knowledge and low energy availability risk in collegiate athletes. J Sci Med Sport. 2024;27(7):451-3.
52. Wasserfurth P, Palmowski J, Hahn A, Krüger K. Reasons for and consequences of low energy availability in female and male athletes: social environment, adaptations, and prevention. Sports Med Open. 2020;6:44.
53. Düking P, Hotho A, Holmberg HC, Fuss FK, Sperlich B. Comparison of non-invasive individual monitoring of the training and health of athletes with commercially available wearable technologies. Front Physiol. 2016;7:71.