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RESEARCH ARTICLE

Prevalence of Low Energy Availability in U.S. Collegiate Athletes: A Systematic Review

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Abstract

Low Energy Availability (LEA) can contribute to broad negative impacts on an athlete's physical health, mental health, and performance. The purpose of this systematic review was to determine the prevalence of Lower Energy Availability in US intercollegiate NCAA or NAIA athletes. Secondarily, this review aimed to compare the potential difference in the prevalence of LEA in male and female athletes. Five databases were searched for peer-reviewed journal articles. Articles eligible for inclusion met the following criteria: 1) investigated U.S. intercollegiate athletes participating in an NCAA or NAIA-sanctioned sport, 2) investigated the prevalence of LEA in participants using self-reported or objective outcome measures, 3) were peer-reviewed, and 4) were a randomized control trial, observational study, prospective cohort study, or cross-sectional cohort study. Ten articles met the inclusion criteria. Prevalence of LEA in athletes varied greatly ranging from 15% to 100% with six studies reporting 50% or greater prevalence. There was limited data on the prevalence of LEA in male athletes, but it ranged from 15% to 45%. In females, the prevalence of LEA ranged from 26.3% to 100%. Comparison between sports was difficult due to differences in reporting methods. Despite the variations in reporting, it appears LEA may be high in both male and female collegiate athletes across a variety of sports; thus, it is important to screen for LEA in all athletes. A gold standard assessment is needed to standardize the literature on LEA and allow for better analysis.

Keywords: Energy, Health, Nutrition, Physical Activity, Sport.

1. Introduction

Athletes competing in NCAA sports have varying nutritional requirements, yet a number of basic nutritional tenants can be applied across numerous sports and divisions. The energy demands of sport refer to the additional energy athletes expend because of their high overall levels of physical activity. Energy demands are typically offset by energy intake, meaning that the consumption of food and drink allows an athlete to satisfy the energy demands for their basic daily functions as well as the additional energy demands of their sport. Energy demands for athletes vary based on multiple factors, including sex, body mass, phase of training, and age. According to Braun et al., most athletes require energy intake between 1,500 kcal and 6,000 kcal per day, and a 70 kg in-season athlete requires between 2,000 kcal and 5,000 kcal per day [1]. Regarding collegiate athletes specifically, a study investigating the positional demands of an NCAA Division III women's soccer match found the mean estimated energy expenditure across all positions to be 1275 ± 321 kcal [2]. When athletes fail to satisfy their energy demands, they are at risk of developing conditions related to their decreased energy availability.

Low energy availability (LEA) in athletes occurs when the athlete's energy intake through nutrition is substantially less than their total daily energy

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expenditure, creating an imbalance between energy needs and energy expenditure [3]. This imbalance can be potentially detrimental to both the athlete's physical and mental health. LEA can be intentional or unintentional by the athlete and may occur as a result of increasing activity, decreasing nutritional intake, or both [4]. LEA is central in the definition of many conditions used to describe the impact of caloric deficit in athletes, such as the female athlete triad (FAT), male athlete triad (MAT), and Relative Energy Deficiency in Sport (RED-S).

The female athlete triad is defined by the interaction between inadequate energy availability, menstrual function, and bone health [5]. LEA in athletes is thought to be the central contributor to the development of the female athlete triad. Severe outcomes of the female athlete triad include eating disorders, amenorrhea, and osteoporosis. Amenorrhea is defined as the absence of menstrual cycles lasting longer than three months, with primary amenorrhea referring to a delay in the age of menarche and secondary amenorrhea referring to amenorrhea occurring after menarche. Multiple previous studies have illustrated that chronic energy deficiency and malnutrition before puberty can stifle growth and sexual development in children and adolescents [6]. Declines in bone mineral density have a direct relationship with increased numbers of missed menstrual cycles, and amenorrheic athletes have a greater relative lifetime risk for stress fractures than eumenorrheic athletes and non-athletes [7]. Despite menstrual function being an aspect of the triad that is unique to female athletes, LEA is not exclusive to female athletes.

The male athlete triad is a less well-established condition that differs from the female athlete triad in that greater reductions in energy availability are needed to produce comparable effects on reproductive and metabolic hormones [8]. The components of the male athlete triad are LEA with or without disordered eating, functional hypogonadotropic hypogonadism, and low BMD with or without bone stress injury [9]. Specific risk factors for low BMD and stress fractures in male athletes include LEA, low body weight (<85% of expected), hypogonadism, average weekly running mileage of greater than 30 miles, and previous history of stress fractures [10]. There currently is no established threshold for LEA beneath which these metabolic effects are observed. The female and male athlete triads have several areas of overlap in their potential outcomes and LEA is an underlying cause in both.

The International Olympic Committee (IOC) coined the term RED-S in 2014 to encompass the impacts of LEA on both female and male athletes [11]. RED-S can have broad negative health effects in males and females including impaired metabolic regulation, cardiovascular health, bone health, endocrine regulation, reproductive function, immunologic response, and psychological wellness [11-12]. RED-S's detrimental physiological effects can lead to negative impacts on the athlete's performance in their sport as well as their mental health. In 2014, the IOC identified 10 areas of potential athletic performance consequences due to RED-S: increased injury risk, decreased training response, impaired judgment, decreased coordination, decreased concentration, irritability, depression, decreased glycogen stores, decreased muscle strength, and decreased anaerobic and aerobic endurance performance [11]. The central cause of these negative health and athletic performance impairments is LEA for those classified with RED-S, just as it is for those that still use the male and female athlete triad classifications.

Outcomes of LEA-associated conditions, such as RED-S and the male and female athlete triads, range from increased risk of injury and poor performance to long-term physiologic and psychologic impacts [11-12]. Due to the potential for detrimental effects on the athlete, the prevalence of low energy availability in athletes needs to be investigated. Determining the prevalence of LEA conditions in athletes can identify sports and personal factors that may put athletes at a greater risk of developing symptomatic LEA conditions and help develop universal screening tools for LEA conditions. The purpose of this study was to conduct a systematic review to determine the prevalence of LEA in US intercollegiate NCAA or NAIA athletes. Secondarily, this review aimed to compare the potential difference in the prevalence of LEA in male and female athletes. The following additional research questions were proposed given sufficient data: 1) Does the prevalence of known secondary health issues for athletes with LEA differ from their peers without LEA, 2) Does the prevalence of LEA in athletes vary per sport?

2. Methods

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines [13]. Five databases (PubMed, CINAHL, SPORTDiscus, Web of Science, and PsycInfo) were searched for peer-reviewed journal articles published between January

1, 2013 to May 30th, 2023. January 2013 was chosen as the start date for the search as the International Olympic Committee's (IOC) consensus statement about RED-S was published in 2014, and articles from 2013 allowed us to include articles that may have influenced the IOC's statement. A broad search for existing systematic reviews regarding low energy availability in college athletes revealed no results. A research librarian assisted in developing the search query and performed the database search. The search query used for PubMed is listed in Appendix 1.

Articles were considered for inclusion if they met all of the following criteria: 1) investigated U.S. intercollegiate athletes participating in an NCAA or NAIA-sanctioned sport, 2) investigated the prevalence of LEA in participants using self-reported or objective outcome measures, 3) were peer-reviewed, and 4) were a randomized control trial, observational study, prospective cohort study, or cross-sectional cohort study. Articles were excluded from the review if they met any of the following criteria: 1) participants were athletes outside of the United States, 2) original research was written in a language other than English, 3) the article was published before January 1, 2013, or 4) research design was a case report or case series.

Following completion of the initial search, results from all five databases were screened and duplicates were removed. The titles and abstracts of articles were screened independently by two reviewers against the specified inclusion and exclusion criteria. The initial level of agreement was documented. Disagreements between the two reviewers on the inclusion or exclusion of a study were resolved by discussion. In the case where the two reviewers could not come to a decision about the study, a third reviewer acted as the arbitrator. Studies that were not found to be relevant at any part of the process were allocated into discard folders. The articles that were found to be relevant following screening of the titles and abstracts were then read in full text by two independent reviewers. The two reviewers independently screened the articles against the specified inclusion and exclusion criteria. Any disagreements between the two reviewers on the inclusion or exclusion of a study were resolved by discussion. In the case where the two reviewers did not come to a decision on a study, the third reviewer acted as the arbitrator.

All articles included in the study were evaluated for rigor and level of evidence. Level of evidence was assessed using the Oxford Centre of Evidence-Based Medicine 2011 [14]. Articles were ranked as Level Evidence 1 to Level Evidence 5 with Level 1 representing the highest level of evidence.

Cross-sectional studies were assessed by an 11-point scale as described by Rostrom [15]. Items included in the study were given a point of 1 and items not included or unable to be determined were given 0 points. The highest possible score was 11 and scores were grouped as follows: 0–3, 4–7, and 8–11 for low, moderate, and high-quality studies, respectively [16]. Cohort studies were evaluated with the Newcastle Ottawa Scale [17]. Articles could score from 0-9 and scores were grouped as follows: 0–3, 4–6, and 7–9 for low, moderate, and high-quality studies respectively [16].

The full text of included articles were independently assessed for rigor and level of evidence by two reviewers utilizing the appropriate scales and the classification of articles were compared. If there was a discrepancy between the levels of evidence or rigor between the two reviewers, it was resolved by discussion or consultation with a third reviewer. Finally, one reviewer extracted data from the articles. In the case where the reviewer was uncertain about the inclusion of data, a second reviewer reviewed the data extraction.

3. Results

Search results from all five databases yielded 928 total articles. The article screening process is outlined in Figure 1. One article had been redacted, and after duplicate removal 573 articles remained, which were then screened by title and abstract. Following title and abstract screening, twenty-seven articles were read in full. Initial level of agreement between reviewers was 74.07%, with twenty-seven articles included by at least one reviewer after full-text screening and seven articles resulting in disagreement between authors. Final 100% agreement on thirteen articles was reached using a third person as arbitrator, which were then assessed for rigor and level of evidence. Three articles were excluded during data extraction due to a repetitive data set. One article from each repetitive data set with the purpose that best matched the purpose of this systematic review was chosen to be included in data analysis. The final article count for data extraction and analysis was ten.

The two reviewers achieved 100% agreement on rigor and level of evidence ratings. Of the ten included articles, three were found to be Level 2 evidence on the OCEBM hierarchy. The three Level 2 evidence articles all scored in the "high" rigor category. The remaining seven articles were found to be cohort studies falling under Level 3 evidence. The Newcastle Ottawa scale was utilized for cohort studies, with three studies scoring 9/9, two studies scoring 8/9, one study scoring 7/9, and one study scoring 6/9. The average score across the seven studies on the Newcastle Ottawa scale was 8/9.

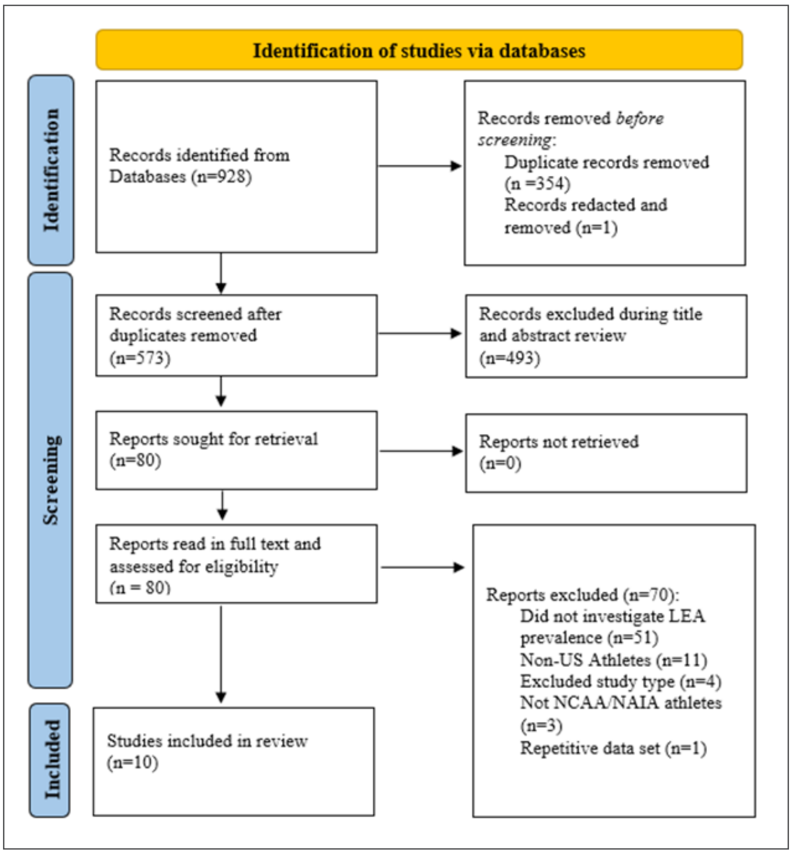

Figure 1. *Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram demonstrating process of study selection utilized in this systematic review*

Table 1. *Article Data*

Study	Participants/ Demographic	Sports	Relevant Outcome Measures	Significant LEA Findings	Secondary Complication Findings
McCormack 2019	n= 60 (males = 27 and females = 33); male = 19.7 ±1.2 yrs; female = 20.3±1.8 yrs	Cross country = 60	Eating Disorder Examination Questionnaire (EDEQ), Food Frequency Questionnaire (FFQ), BMD, EA	• 11 (42.3%) male runners and 8 (28.6%) female runners had an EA of less than 30 kcals kg−1FFM. • 13.6% of male controls and 29.2% of female controls had an EA of less than 30 kcals kg−1FFM.	• NA
Reed 2013	n=19 females; 19.23 ±.23 yrs	Soccer = 19	EEE, EI, EA, BMI, %BF, FM, LBM, Eating Disorder Inventory 2	• LEA was observed in 5/19 (26.3%), 5/15 (33.3%), and 2/17 (11.8%) of athletes during the pre, mid, and post season respectively.	• EA was inversely related to body dissatisfaction (r =-0.62, P = 0.017) and drive for thinness (r =-0.55, P = 0.041) during mid-season
Moris 2022	n = 44 males; 20.4± 0.2 yrs	Cross country = 5, soccer = 7, wrestling = 10, basketball = 4, track and field = 4, golf = 5, baseball = 9	EI, EEE, EA, BMD, RMR ratio, total testosterone (TT), and calculated free testosterone (cFT), FFM	• 5 of 34 (15%) participants had LEA of 20 kcal/kg FFM. n=1 each from cross country, wrestling, track, golf, and baseball.	• 16 of 44 participants (36%) had an RMR ratio ≤0.90 suggestive of metabolic adaptation secondary to LEA. • There was no significant correlation between EA, BMD, TT and cFT.

Shriver 2013	n = 45 females; 20.0 ±1.5 yrs	Soccer = 20, basketball = 18, track/cross country = 7	EI and RMR	● 91% of the participants did not meet their energy goals ● Average daily energy intake = 1,939±604 kcal	NA
Torres-McGehee 2021	n= 95 females; equestrian 19.4±1.3 yrs; soccer 19.8±1.3 yrs; beach volleyball 19.9±1.5 yrs; softball 19.6±1.1 yrs; volleyball 19.2±1.3 yrs	Equestrian =28, soccer = 20, beach volleyball = 18, softball =17, volleyball =12	RMR, EI, TDEE, EEE, EDI-3, EDI-3 Symptom Checklist	● 76.8% of athletes had LEA ○ 23 (82.1%) of Equestrians ○ 10 (83.3%) of volleyball ○ 17 (100%) of softball ○ 17 (94.4%) of beach volleyball ○ 6 (30%) of soccer players	● 73.9% of equestrian, 70.0% of volleyball, 82.4% of softball, 70.6% of beach volleyball, and 66.7% of soccer athletes demonstrated LEA and an eating disorder risk
Yli-Piipari 2019	n=18 females; 19.86±1.35 yrs	Tennis = 5, soccer = 13	EEE, EI, EA, BMI	● 83.3% of athletes demonstrated LEA. ● Average EA was -581±413kcal.	NA
Smith 2022	n = 19 females; 20.3 ± 1.2 yrs	Competitive cheer = 19	RMR, EDI-3, EDI-3 Symptoms Checklist, BMD, EI, menstrual history, FFM, EEE, TDEE, Hormonal Menstrual Cycle Blood Assessment	● 100% of participants demonstrated LEA ● 52.6% demonstrated LEA with an ED risk ● 47.4% demonstrated LEA without ED risk. ● Mean EA = 12.48 (kcal/kgFFM/day)	● 0% demonstrated low BMD ● 52.6% of athletes were at self-reported risk of menstrual dysfunction ● 14.2% demonstrated hormonal menstrual dysfunction.
Purdom 2023	n = 23; (males = 13 and females = 10); 19.7 ± 1.5 yrs	Women's volleyball = 5, women's track = 5, men's track =4, football = 1, men's basketball = 8	BF%, FFM, EI, EA, Blood pressure	● 14/23 (60.9%) of athletes were calorie deficient	● Moderate relationship between high blood pressure and LEA (r = 0.56) with 14/23 having HBP.
Beermann 2020	n=41;(males = 21, females = 20); males: 19.6±1.2 yrs, females: 20.2 ±1.7 yrs	Cross country = 41	Block Food Frequency Questionnaire, EEE, EI, BFLM, FFM, BF%, EA	● 43% of athletes, 9 males (45%) and 7 females (41%), had clinically low EA.	NA
Magee 2020	n = 18 females; 19.2±1.1 years	Soccer = 18	BMI, BF%, EA, LEAF-Q, Abridged Sports Nutrition Knowledge Questionnaire (ASNKQ)	● 67% of athletes had LEA based on diet analysis and energy expenditure ● 56.3% had LEA based on LEAF-Q	NA

Appendix of abbreviations: Body fat percent = BF%, body mass index = BMI, bone free lean mass = BFLM, bone mineral density = BMD, Eating Disorder Inventory-3 = EDI-3, energy availability = EA, energy intake = EI, exercise energy expenditure = EEE, fat free mass = FFM, fat mass = FM, lean body mass = LBM, Low Energy Availability in Females Questionnaire = LEAF-Q, resting metabolic rate = RMR, total daily energy expenditure = TDEE

3.1 Measurement of LEA

The data that were extracted from each article is included in Table 1 and includes participant demographics, sports, outcome measures used, results, and any secondary health complications. The methods used to calculate LEA varied by study; therefore, a meta-analysis could not be performed. Seven of the studies reported prevalence of LEA based on the calculation of calories per kilogram of fat free mass (kcal/kg/FFM), and six of the seven articles placed the LEA cut off at ≤30kcal/kgFFM [18-24]. One article that calculated LEA based on kcal/kg/FFM set the cutoff for LEA at ≤20kcal/kg/FFM [21]. Three articles used caloric deficit to determine LEA in athletes [25-27]. Two articles utilized similar methods estimating athlete's caloric intake via a multi-day diet log and estimating energy expenditure from resting metabolic rate (RMR) multiplied by an appropriate physical activity factor determined for the athlete [25, 27]. The third study also utilized a multi-day dietary food log to estimate caloric intake, but instead estimated energy expenditure from an accelerometer activity tracker [26].

3.2 Prevalence of LEA

Participants from the ten articles totaled 382 college athletes including 277 female athletes (72.5%) and 105 male athletes (27.5%). Prevalence of LEA reported in athletes varied greatly among the ten included articles. The overall prevalence reported in the included articles, regardless of sport or sex, ranged from as low as 15% up to 100% [21-22]. Overall, there was one article that denoted LEA prevalence below <25% [21], three with percentages between 25 and 50% [18-19, 23], two other articles reporting percentages between 50 and 75% [24, 27], and four articles reporting percentages between 75 and 100% [20, 22, 25-26].

One article reported LEA prevalence at three different timepoints during the sports season [19]. The authors of this article found that 25-50% of athletes displayed LEA at pre- and mid-season points, with this value decreasing in the post-season to only 11.8% of athletes displaying LEA [19].

3.3 Male versus Female Athlete Prevalence

There was limited data on the prevalence of LEA in male athletes. Four articles included male athletes, with only one of these articles investigating males alone. The prevalence of LEA in male athletes ranged from 15% to 45% [21, 23]. In comparison, nine articles included female athletes with six of these articles reporting on females alone. In the articles that separated data by sex, the prevalence of LEA in female athletes ranged from 26.3% up to 100% [19, 22].

Of the ten articles included, three included both male and female athletes. Despite three articles including both sexes, comparing prevalence between male and female athletes is difficult given that only two studies directly compared the two. The two articles directly comparing male and female athletes assessed prevalence of LEA in cross country runners. Both articles reported a similar prevalence in male runners (45% and 42.3%) yet differed in the prevalence in female runners (41% and 28.6%) [18, 23].

3.4 Sports

Despite the included articles investigating prevalence of LEA in athletes across 13 different sports, comparison between sports is difficult due to differences in reporting methods. Four articles that included multiple sports only gave the overall prevalence for all athletes included instead of breaking down prevalence per sport. Seven sports had LEA prevalence explicitly reported. Prevalence of LEA in soccer athletes was reported in three studies and ranged from 26.3% to 67% [19, 24]. Two studies reported prevalence in cross-country athletes with rates of LEA broken down by sex and sport ranging from a low of 28.6% to a high of 45 [18, 23]. The remaining five sports reporting LEA prevalence were reported by one of two articles. Smith et al. included only competitive cheer athletes and reported a prevalence of 100% [22]. Torres-McGehee et al. reported on four sports including softball (100%), beach volleyball (94.4%), volleyball (83.3%) and equestrian (82.1%) [20].

3.5 Secondary Complications

Limited data was available on secondary complications with only half the articles including information on secondary health complications. One article investigated athletic/aesthetic concern. Reed et al. found that body dissatisfaction ($r = -0.62$, $p = 0.017$) and drive for thinness ($r = -0.55$, $p = 0.041$) scores assessed by the Eating Disorder Inventory 2 were inversely related to LEA in female soccer players [19]. One included article investigated LEA with eating disorder risk, as measured by the Eating Disorder Inventory-3 (EDI-3) and the Eating Disorder Inventory-3 Symptom Checklist (EDI-3 SC), and found that 73.9% of equestrian, 70.0% of volleyball, 82.4% of softball, 70.6% of beach volleyball, and 66.7% of soccer athletes that demonstrated LEA also had an eating disorder risk [20].

Three articles looked at different areas of physiological adaptations. The study by Moris et al. investigated total testosterone and calculated free testosterone levels but found that there was no significant correlation between these variables and EA or BMD [21]. Moris et al. also found that 36% of male athletes had a resting metabolic rate ratio ≤0.90, indicative of metabolic adaptation due to LEA, despite reporting that only 15% of athletes demonstrated LEA from dietary intake and energy expenditure [21]. Purdom et al. concluded that there was a moderate relationship ($r = 0.56$) between high blood pressure and LEA in male and female college athletes [27]. Smith et al. reported LEA prevalence of 100% and also investigated prevalence of menstrual dysfunction in a population of female competitive cheerleaders [22]. Smith et al. found that 14.2% of athletes demonstrated hormonal menstrual dysfunction and 52.6% self-reported risk of menstrual dysfunction measured via participant survey and EDI-3 SC [22].

4. Discussion

The primary objective of this systematic review was to determine the prevalence of LEA in US intercollegiate athletes. Across the ten articles included in this systematic review, the prevalence of LEA ranged vastly from 15% to 100% of athletes [21-22]. The variability in the reported prevalence of LEA and in the reporting methods of these articles makes it difficult to determine a true average prevalence in US collegiate athletes. The greatest barrier to determining the true prevalence of LEA in collegiate athletes is the current lack of a gold standard tool or method to identify and report LEA. This lack of standardization resulted in discrepancies both in outcome measures utilized to estimate LEA and in cutoff scores used to define LEA, making comparisons of prevalence across articles difficult.

Of the seven included articles that used the calculation of kcal/kg/FFM, six defined their LEA cutoff as 30 kcal/kg/FFM [18–20, 22–24] and one defined it as 20 kcal/kg/FFM [21]. The threshold for LEA is defined as the value below which the manifestation of physical symptoms of RED-S can arise [28]. While 30 kcal/kg/FFM is often considered the universal threshold for LEA in females utilized in research, its accuracy is debated and not absolute [28]. The LEA cutoff score for males is even less well-understood due to a lack of available research, but it is believed to be lower than the female cutoff score [28].

The remaining three included articles used caloric deficit to define LEA by estimating an athlete's caloric intake and caloric energy expenditure over a set time period [25–27]. This method of defining LEA often relies on self-reported calorie tracking and dietary intake as well as estimates of energy expenditure based on resting metabolic rate or activity tracking. Interestingly, it appeared articles using this method reported higher levels of LEA prevalence with rates of 91%, 83.3%, and 60.9% respectively [25-27].

When reviewing the literature not all articles utilized appropriate markers of LEA. While removed during the screening process, one article investigating the relationship between the female athlete triad and the risk of bone stress injuries defined LEA criteria as a past or current diagnosis of an eating disorder [29]. The authors stated this criteria for LEA was utilized as the data from historical preparticipation physical exams lacked the needed information to calculate LEA in an appropriate manner [29]. Eating disorders and disordered eating patterns can contribute to an athlete under fueling and therefore are a risk factor for developing LEA [28]. However, these two terms are not synonymous and eating disorders are not the sole determinant of LEA in athletes.

The lack of a standardized way of assessing LEA is an issue that the IOC also identified in their 2023 consensus statement on RED-S [28]. The IOC recognized the difficulties with measuring EI and EEE in athletes during an athletic season but proposed the use of protocols to "achieve a harmonised time-course for assessment" and for "standardising the errors and limitations of the assessment, and balancing the issues of time and resource burden, feasibility and measurement precision" [28]. Despite this proposition, there is no standardized method for assessing athlete LEA at this time.

The secondary questions of this systematic review were unable to be fully answered due to reporting variations and the amount of data that was provided. There was insufficient data regarding secondary health conditions related to LEA to make any accurate conclusions or comparisons between athletes with and without LEA. Although it appears there are some potentially related conditions including risk for disordered eating [19, 28] menstrual dysfunction [22], and hypertension [27].

Although thirteen sports were represented in this systematic review, specific data regarding LEA was only differentiated for six sports: cross country, competitive cheer, softball, beach volleyball, volleyball, and equestrian. This congregate data made it difficult to make accurate comparisons of the prevalence of LEA per sport and resulted in an incomplete answer to our secondary question. Additionally, sports involving large amounts of running, such as cross country and soccer, predominated the sports and athletes investigated in the included studies, while athletes involved in sports including wrestling, beach volleyball, gymnastics, and swimming/diving were underrepresented in the collected data.

Although the high caloric demands of running warrant sufficient investigation into energy demands and availability, athletes of other sports that do not involve running are also significantly impacted by low energy availability. This systematic review identified five non-running sports with high levels of LEA prevalence. Competitive cheer, equestrian, volleyball, softball, and beach volleyball athletes all demonstrated a high prevalence of LEA ranging between 82.1% and 100% from the data included in this systematic review [20,22].

The participants investigated across the included studies primarily consisted of female athletes at approximately 72.5% of the total participants, whereas males made up just 27.5% of the total participants. Despite alteration of nomenclature to be more inclusive of deficits in energy availability across sexes, females continue to be the primary sex investigated in these types of studies. Our investigation into the prevalence of LEA across existing studies revealed similar significant rates of LEA in both male and female cross-country runners, suggesting that it is important for researchers to appropriately recognize male athletes as potentially having LEA.

4.1 Implications for Healthcare Providers

Despite the variation in numbers and methods to calculate, with prevalence between 15 to 100% it appears the prevalence of LEA is high with 6 out 10 studies reporting prevalence of 50% or greater [21,22]. It is important to screen both male and female athletes of running and non-running sports for LEA. While limited, based on the data on LEA and secondary health issues, healthcare providers should be aware of and look for secondary health complications in those with suspected LEA and its associated conditions such as RED-S. There is a need for a gold standard assessment of LEA. The methods and data from the included studies in this review demonstrate the difficulties of establishing this gold standard. Each athlete must be assessed individually and healthcare practitioners should utilize the International Olympic Committee Relative Energy Deficiency in Sport Clinical Assessment Tool Version 2 (IOC REDs CAT2) protocol to screen athletes for LEA [28].

5. Limitations

Multiple limitations have been identified that impacted conclusions of this systematic review. The term "low energy availability" is relatively new and much of the information on RED-S, one of the main LEA-related conditions, has been written within the past 10 years. With its recent acknowledgement, the term may not yet be appropriately understood resulting in some studies collecting inappropriate data to demonstrate LEA. Furthermore, there was limited overall data on secondary health complications due to low energy availability, resulting in insufficient data to answer our additional research questions. Lastly, the lack of a gold standard for identifying LEA made the extracted data difficult to compare across studies as a variety of outcome measures were utilized. Further research should prioritize the investigation of LEA in a standardized method for both male and female athletes as well as explicitly report data for athletes of each included sport. Further research should also consider the role of athlete identity when investigating LEA. Athlete identity is defined as "the degree to which an individual identifies with the athlete role" [30]. While having a high athletic identity is not always a negative, those with a strong athlete identity are more likely to frame things such as injury, diet, and stress in terms of their impact on athletic functioning compared to those with a weaker athletic identity [30]. Therefore in highly aesthetic sports, having a high athletic identity may impact an athlete's perceptions of how they look and eat, subsequently altering their energy availability and overall health status [31].

6. Conclusion

The true prevalence of LEA in US collegiate athletes is difficult to estimate given the vast range of reported prevalence and the variation in reporting methods but appears to be occurring at a high rate. There is also insufficient data to compare prevalence of LEA between sports and the development of secondary health effects. Despite these discrepancies, it is apparent that LEA can and is affecting both male and female collegiate athletes at a variable rate. Identification of a universally recognized gold standard for assessing LEA in athletes would greatly aid future research.

Declarations

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Appendix 1: PubMed Search Terms

((“Energy Metabolism”[Mesh:NoExp] OR “Basal Metabolism”[Mesh] OR “energy intake”[MeSH] OR “Nutrients”[Mesh:NoExp] OR “nutritional requirements”[MeSH] OR “nutritional status”[MeSH] OR “Sports Nutritional Physiological Phenomena”[Mesh] OR “Sports Nutritional Sciences”[Mesh]) OR (“low energy”[tw] OR “energy availability”[tw] OR “energy metabolism”[tw] OR “energy metabolisms”[tw] OR “energy expenditure”[tw] OR “energy expenditures”[tw] OR “energy demand”[tw] OR “energy demands”[tw] OR “energy imbalance”[tw] OR “energy imbalances”[tw] OR “energy balance”[tw] OR “energy balances”[tw] OR “energy need”[tw] OR “energy needs”[tw] OR “female athlete triad”[tw] OR “male athlete triad”[tw] OR “relative energy deficiency”[tw] OR “basal metabolism”[tw] OR “basal metabolisms”[tw] OR “energy intake”[tw] OR “calorie intake”[tw] OR “caloric intake”[tw] OR “macronutrient”[tw] OR “macronutrients”[tw] OR “nutritional requirement”[tw] OR “nutritional requirements”[tw] OR “nutrition requirement”[tw] OR “nutrition requirements”[tw] OR “dietary requirement”[tw] OR “dietary requirements”[tw] OR “nutritional status”[tw] OR “nutrition status”[tw] OR “sports nutritional”[tw] OR “sports nutrition”[tw] OR “exercise nutritional”[tw] OR “exercise nutrition”[tw]))

AND

((“Athletes”[Mesh]) OR (“athlete”[tw] OR “athletes”[tw]))

AND

((“Universities”[Mesh]) OR (“university”[tw] OR “universities”[tw] OR “college”[tw] OR “colleges”[tw] OR “collegiate”[tw] OR “intercollegiate”[tw]))