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Nutrition Education and the Effects on Athletic Performance in Collegiate Athletes with Low Energy Availability

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Abstract

Current research suggests that collegiate athletes lack nutritional knowledge needed for optimal athletic performance. The absence of basic nutritional knowledge in college athletes puts them at an increased risk for RED-S and its sports performance consequences. The objective of this narrative review is to evaluate the literature on low energy availability in collegiate athletes and determine if nutrition education can improve athletic performance. Multiple studies concluded that nutrition education may improve dietary intake in collegiate athletes, while there was one contradicting study that found that athletes improved nutritional knowledge but did not improve dietary intake. 3 studies found that low energy availability results in negative effects on athletic performance. The research is limited on how nutrition education and knowledge influences athletic performance. It can be predicted that increased knowledge may improve low EA thus improving athletic performance in collegiate athletes. Future research should focus on the relationship between having a registered dietitian as part of the athletic team and nutrition knowledge, behaviors, and athletic performance in athletes. Additionally, interventions provided by a registered dietitian may fill the knowledge gap and improve health and performance in athletes.

Introduction

Any athlete desires to be the best they can be and emphasis on proper nutrition has been the foundation for great athletic health and performance. As defined by the International Olympic Committee (IOC), relative energy deficiency in sport (RED-S) is the inadequacy of caloric intake and/or excessive energy expenditure that results in impaired physiological function including metabolic rate, menstrual function, bone health, immunity, protein synthesis, cardiovascular health (Mountjoy 2014). Previously, this syndrome was identified as the female athlete triad which involved active women with low energy availability (EA), menstrual dysfunction, and low bone mineral density. Similar to the female athlete triad, RED-S is a new model that expands on the concept to include the effects of energy deficiencies on physiological function, health, and athletic performance in both male and female athletes. Athletes who fail to meet the sport nutrition guidelines for energy, fluid, and macronutrients are at risk for low EA and RED-S (Klein 2021). However, it is important to note that low EA can occur with or without an eating disorder (Melin 2014).

Most of the literature on low EA has targeted female athletes, however, it has been reported to appear in male athletes as well. In addition, low EA in males is prevalent in the same at risk sports as females. Those at risk include weight sensitive sports where leanness plays a critical role in performance, appearance, or there is a requirement to meet a competition weight category (Mountjoy 2014). There is developing evidence of body image issues and unhealthy dietary behaviors within male athletes (Burke 2018)

Low EA is the main factor that causes RED-S and its health and performance consequences. Energy availability involves energy intake in relation to the energy cost of exercise and these components are important when considering sports nutrition strategies (Thomas 2016). In a state of low EA, the body cannot support all physiological functions needed to maintain optimal health as a result of the low energy. There is significant research that suggests athletes with low EA are more likely to have potential performance effects such as decreased muscle strength, decreased endurance performance, increased injury risk, decreased training response, impaired judgment, decreased coordination, decreased concentration, decreased glycogen stores, irritability, and depression (Williams 2019). These serious implications result in short and long term decline in optimal health and performance. Preventative educational programs are essential for early intervention to prevent these consequences.

Nutrition knowledge is an important component of meeting sports nutrition guidelines and many of these athletes suffer from low EA as a result of lack of knowledge. Sports nutrition knowledge can be defined as understanding of nutritional strategies that are specific to training, athletic performance, and recovery from a sport beyond that of general nutrition knowledge (Klein 2021). The goal of sports nutrition is to provide the right food, energy, nutrients, and fluid so that athletic performance can be optimized. An athlete with poor nutrition knowledge cannot be expected to make optimal dietary choices. There are many barriers including stress and time of being a full-time student and college athlete, cooking skills, financial constraints in addition to poor nutrition knowledge that can lead to improper fueling and recovery from sport. Nutrition interventions should be personalized to the individual athlete and take into consideration the event, personal goals, food preferences, and responses to various strategies (Thomas 2016). In addition, sports nutrition education should be provided to the individual athlete, as well as the entire team, coaches, athletic trainers, physiologists, or foodservice staff in order to achieve optimal success.

There is a lack of evidence in evaluating EA in athletes in relation to nutrition knowledge and associated conditions on sport performance. By improving nutrition knowledge among athletes, risk factors of RED-S may decrease. The purpose of this narrative review is to evaluate the literature on low

energy availability in college athletes and determine if nutrition education can improve athletic performance.

Methods

The primary search engine used for this research was PubMed and included articles from August 2009 through December 2021. Search terms included low energy availability, athlete, nutrition, nutrition knowledge, nutrition education, college, and athletic performance. A review of all potential articles for inclusion criteria was conducted. Articles that are included in this review are if the population was college athletes, there was low EA within the athlete population, or consisted of nutrition education and athletic performance. In addition, articles were included regardless of study design or whether the study was conducted in the United States or not. There are 14 studies included in this narrative review based on the inclusion criteria.

Literature Review

Low energy availability can negatively affect athletic performance

For optimal athletic performance, athletes need to follow sports nutrition guidelines to properly fuel and recover from their sport. Athletes who do not follow the recommendations to meet individual energy needs could be at risk for low EA and its performance consequences. There is significant research that suggests that low EA can negatively affect athletic performance.

Ackerman and colleagues (2019) conducted a cross-sectional study that investigated the correlation of low energy availability and health and performance outcomes of RED-S. This study administered an online questionnaire to 1000 female athletes which assessed potential physiological and performance reductions pertaining to low EA. An athlete was considered to have low EA when there was a positive response to one or more of the three eating disorder/disordered eating screenings. Results of this study showed that approximately half of the athletes that were surveyed had a positive screening for low EA. Those athletes that suffer from low EA were more likely to experience negative performance issues as a result. This included decreased training response, impaired judgment, decreased coordination, irritability, depression, and decreased endurance performance. Lastly, the athletes with low EA were more likely to experience negative health consequences of RED-S such as menstrual dysfunction, poor bone health, metabolic issues, cardiovascular impairment and gastrointestinal dysfunction when compared to athletes with adequate EA (Ackerman 2019).

Keay and colleagues (2019) conducted a randomized controlled trial to evaluate how nutrition education affected bone health and performance over the duration of race season in competitive male cyclists. The study included 45 participants who were matched in pairs based on z-scores for lumbar spine bone mineral density (BMD). One participant from each pair was randomly selected to receive nutrition education that focused on maintaining adequate energy availability and proper fueling around training sessions. Results of this study showed that there was improved bone health and performance of male cyclists at risk of RED-S as a result of nutritional and skeletal loading. There was a significant increase in lumbar spine BMD found in the intervention group which indicates that nutritional and skeletal loading measures were effective at improving bone health. For the non-intervention group that did not change either nutrition or off-bike exercise, there were no changes in lumbar spine BMD. Some cyclists displayed negative nutrition behaviors and experienced a significant decrease in lumbar spine BMD during the study period. These participants intentionally restricted dietary intake in an attempt to reduce body weight for the race season to improve race results. However, fatigue, illness, and injury were reported among these athletes indicating that low EA can lead to decreased athletic performance (Keay 2019).

Vanheest and colleagues (2014) investigated the effects of ovarian suppression and energy deficit on swimming performance in junior elite female swimmers. This study consisted of ten athletes that were involved in a twelve week competitive swim training season and assessed every two weeks. Daily diary entries were completed throughout the study and consisted of questions about sleep, diet, injury, illness, stressors, and menstrual cycle. Anthropometrics, maximal 400 meter freestyle swim, energy expenditure and diet records were also assessed. Participants were divided into two groups according to ovarian status at baseline. The two groups were cyclic menstrual function (CYC) and ovarian suppressed (OVS) menstrual function group. Results of this study showed that EA in the cyclic group was significantly greater than the ovarian suppressed group. There was a correlation between decreased sports performance and OVS, low metabolic hormones, and low EA and EI. The CYC group improved by 8.2% in the swim performance with a faster time trial while the OVS group declined by 9.8%. This concludes that low EA can negatively affect athletic performance (Vanheest 2014).

In summary, low EA can occur across various sports and all athletes have the potential of developing RED-S. The three studies concluded that low EA can result in performance consequences such as decreased training response, impaired judgment, decreased coordination, irritability, depression, decreased endurance performance, fatigue and increased injury risk.

Nutritional knowledge of collegiate athletes

An important component of combating low EA in college athletes is ensuring that these athletes have the nutritional knowledge to meet the recommended sports nutrition guidelines. The research suggests that athletes lack the nutritional knowledge needed to make appropriate nutrition decisions based on their sport. Low EA results in impaired performance, therefore, it is essential that athletes have appropriate dietary behaviors in relation to their activity.

In a study by Jagim and colleagues (2019) investigated nutritional intakes in relation to recommended values, perceived intakes and needs of NCAA Division II female lacrosse players. Twenty athletes participated and total daily energy expenditure (TDEE), body composition, and dietary intake were evaluated. To assess the perceptions of dietary intake and dietary needs, a questionnaire was administered to participants and was compared to the International Society of Sports Nutrition (ISSN) energy and macronutrient recommendations as well as established dietary guidelines for their sport. The results of this study displayed significant differences in energy and macronutrient recommendations in comparison to actual intakes in these athletes. Specifically, athletes believed their protein needs were less than what was actually consumed. Additionally, athletes did not meet energy and macronutrient recommendations in comparison to the "low" estimate of energy requirements for their sport thus putting them at risk for low EA and its performance consequences. This suggests that athletes may lack basic understanding of nutritional needs and could benefit from basic nutrition education to understand appropriate nutritional needs based on their sport (Jagim 2019).

A study by Hoogenboom and colleagues (2009) examined nutritional knowledge in female collegiate swimmers and how they apply their knowledge to daily eating habits. There were eighty five participants in this study who took a basic nutritional knowledge survey and completed a 24-hour dietary recall. Results from the nutritional knowledge survey displayed that participants demonstrated basic knowledge of nutrition. However, dietary intake showed that 90% of the participants did not meet the RDA for at least one macronutrient. In addition, participants believed that carbohydrates and protein had contrasting caloric values. This false conclusion may have resulted in an increase in protein intake and a decline in carbohydrate intake. 55.3% of athletes in the study consumed above the RDA range for fat which could be a result of decreased carbohydrate intake as well. Lastly, 76% of participants failed to meet caloric intake recommendations suggesting that they are performing at an energy deficit which can negatively impact performance. The nutritional questionnaire had a mean score of 71.75% indicating fair nutritional knowledge. Overall, these results suggest that despite having nutritional knowledge, participants are not applying their knowledge to their intake habits. Additional

nutrition education may be favorable for swimmers to improve energy availability and performance (Hoogenboom 2009).

An observational study by Magee and colleagues (2020) examined the prevalence of low energy availability in collegiate women soccer players as well as the relationship between nutritional knowledge, energy availability and dietary intake. Eighteen participants completed a body composition assessment, sport nutrition knowledge questionnaire, LEAF-Q questionnaire that screened for low EA, and recorded a dietary intake. Results from the study showed that 67% of athletes expressed low EA. These athletes had a lower daily mean energy intake of 30 kcals/kg/day in comparison to the recommended 40-60 kcals/kg/day for their sport. This group consumed lower amounts of carbohydrates and relative fat than athletes without low EA. There were no significant differences in absolute and relative protein consumed or absolute fat intake. The average energy availability examined was below the threshold used to classify those with low EA. It is important to note that the comparison group had access to nutritional staff while this study did not. Additionally, the athletes with low EA scored lower on the sports nutrition knowledge questionnaire compared to athletes without low EA. A higher fat mass was also observed in athletes who scored lower on the nutrition knowledge questionnaire. Overall, the prevalence of low EA among collegiate women soccer athletes is high as many participants in this study failed to meet multiple nutritional recommendations for their sport. Additionally, low EA was more prevalent among athletes who scored lower on the nutrition knowledge questionnaire. Sports nutrition education may be beneficial for this population to understand dietary recommendations, avoid low EA and its potential performance consequences (Magee 2020).

Jagim and colleagues (2021) examined the relationship between sports nutrition knowledge, body composition, and body weight goal in NCAA Division III collegiate athletes. 67 athletes participated and completed a body composition assessment, sports nutrition knowledge questionnaire, and an internally developed questionnaire that investigated perceived dietary requirements and body weight goals. Body composition was assessed using a Bod Pod and determined body fat percent, fat-mass, and fat-free mass. Participants completed the Abridged Sport Nutrition Knowledge Questionnaire (A-SNKQ) and results were interpreted from poor to excellent based on the number of questions answered correctly. The perceived dietary requirements questionnaire was completed prior to the season and assessed perceived energy and macronutrient intake on a typical day and compared to the calculated energy and macronutrient intake. Results of this study showed an inverse relationship between body fat percentage and fat mass and sports nutrition knowledge. This suggests that nutrition knowledge is associated with body composition as increased knowledge resulted in lower body fat percentage and fat

mass values. The sport nutrition knowledge questionnaire was categorized as poor with an average of 48% of questions answered correctly. Sports nutrition knowledge scores and perceived energy requirements showed a positive relationship predicting that increased knowledge may result in meeting energy requirements. Athletes reported lack of nutrition knowledge as one of the barriers to meet nutrition requirements for their sport which justifies the need for nutrition education in this population (Jagim 2021).

Klein and colleagues (2021) evaluated sports nutrition knowledge in NCAA Division III collegiate athletes to assess dietary patterns and to determine where athletes are getting sources of nutrition information. The study consisted of 331 male and female athletes and participants completed a dietary habits and sports nutrition knowledge survey. Results of this study placed athletes at risk for poor dietary intakes that could affect training, recovery, and performance as a result of the low sport nutrition knowledge scores. The average score percentage was between 35% and 40% with factors such as sex, previous nutrition course, or sport considered. Less than half of the athletes reported eating breakfast every day which could be a potential barrier to meeting total energy needs and females were more likely to choose fruits or vegetables as snacks compared to males. However, athletes in this study were aware of dietary practices in regards to skipping meals and following guidelines for pre- and post-workout/practice nutrition. Athletes in this study reported eating a meal consisting of carbohydrates and protein within one hour pre-workout and one to two hours post-workout which is consistent with sports nutrition guidelines. Despite having poor nutrition knowledge scores, athletes were aware of some sport dietary practices and further nutrition education could enhance nutritional knowledge (Klein 2021).

Overall, collegiate athletes lack the nutritional knowledge needed to make appropriate nutritional decisions based on their sport and to enhance athletic performance. In the studies, athletes were found not meeting energy requirements putting them at risk for low EA. Additionally, athletes may have indicated fair nutrition knowledge but making appropriate nutritional decisions based on their sport was absent. An athlete with poor nutrition knowledge can lead to improper fueling and recovery from sport resulting in performance consequences. Interventions are needed to improve nutrition knowledge in college athletes for optimal performance and lower the risk for RED-S.

Nutrition knowledge influences athletic performance in college athletes

There is limited research that investigates the relationship between nutrition knowledge and athletic performance in college athletes. Athletes need sufficient nutrition knowledge to improve dietary intake and thus improving athletic performance.

A cross-sectional study by Folasire and colleagues (2014) examined nutrition knowledge and practice and the effects of athletic performance. This study involved 110 undergraduate collegiate student athletes in Nigeria. A questionnaire was administered to the participants regarding nutrition knowledge and practice. Information about participants' dietary pattern was obtained using 24-hour diet recall and food frequency questionnaire. As an indirect measure of athlete performance, handgrip strength was assessed. Results observed a significant positive correlation between hand grip strength and energy intake concluding that adequate energy intake may be optimal for athletic performance. However, hand grip strength is not a significant predictor of athletic performance. A majority of athletes in this study did not meet the recommended macronutrient intakes. 58.2% of athletes had good nutrition knowledge scores. A majority of athletes responded correctly that carbohydrates are the main source of energy, athletes should consume at least 3 meals per day, and were aware that food intake increases since they are athletes. This study found no correlation between nutrition knowledge, nutrition practice and hand grip strength but rather when nutrition knowledge and practice is aimed at meeting energy requirements then athletic performance can be expected (Folasire 2014).

Rossi and colleagues (2017) examined how sports nutrition education influenced dietary intake, knowledge, body composition, and performance in NCAA Division I baseball players. This study is already discussed in a previous section, however, it is important to note the effects of athletic performance as a result of nutrition knowledge. Findings displayed decreased body fat percentage which could be a result from increased protein consumption in the intervention group. Reductions in fat mass may have also contributed to improvement in shuttle run performance within the intervention group. Overall, nutrition education with reinforcement sessions proved to be successful in improving nutritional status, body composition, and shuttle run performance (Rossi 2017).

Hull and colleagues (2017) conducted a cross-sectional survey to evaluate the differences between receiving nutrition education from a sports dietitian or a strength and condition coach (SCC) as the main source of information and how that affects dietary habits of NCAA Division I baseball players. There were 99 participants in this study. The sports dietitian provided nutrition education and individual counseling to athletes with the primary purpose to improve athlete performance and recovery. A survey questionnaire was administered and included information such as sport participation, general dietary habits, breakfast, hydration, nutritional supplements, post-workout nutrition, nutrition during team

trips, nutrient periodization, and demographics. Results of the present study showed significant differences in dietary habits between baseball athletes who worked with the sports dietitian and those who did not. These habits included decreased consumption of fast food, caffeinated beverages, increased consumption of daily multivitamin, and decreased consumption of fast food on team trips. The SCC group experienced negative effects from dehydration and frequent hunger episodes during training, practice, or competition compared to the sports dietitian group. Poor fueling can result in decreased performance, muscle protein catabolism, and impaired recovery status. Access to a registered dietitian may help guide NCAA athletes to improved adherence to nutrition performance principal and therefore improved athletic performance and recovery (Hull 2017).

The studies concluded that an increase in nutritional knowledge can result in enhancement of performance indicators such as body composition or improved shuttle run performance. Therefore, the research suggests that increased knowledge may improve low EA which would result in improving athletic performance.

Nutrition education affects nutrition knowledge and dietary intake in college athletes

An intervention that may increase nutrition knowledge in college athletes is to provide nutrition education to improve dietary intake. Athletes lack the nutritional knowledge needed to make appropriate nutritional decisions based on their sport to enhance athletic performance. The research suggests that nutrition education may improve nutrition knowledge and dietary intake in college athletes and in return improve performance.

Valliant and colleagues (2012) evaluated dietary intake, nutrition knowledge, and whether nutrition education improved dietary intake of NCAA Division I collegiate female volleyball players over the course of two off-seasons. Eleven athletes participated in this study. The first off season was used as the non-intervention baseline assessment using 3-day food records that were gathered at the beginning and the end of the off-season with no previous nutrition education. The second off season was used as the intervention group and 3-day food records were collected once a month for four months total. During this second off season, participants received dietary education that was individualized to each athlete with emphasis on increasing nutrition knowledge of the types and amounts of foods specific to their individual dietary needs and activity level. A sports nutrition knowledge survey was also administered to the participants at the beginning and the end of the intervention season. The individualized nutrition intervention was conducted by a Registered Dietitian and met with each participant four times during the intervention season. Results of this study showed that during the off-

season, participants failed to meet energy intakes for physically active females indicating low EA within these athletes. The recommended energy requirement for this population is 37-41 kcal/kg of body weight and the participants had a mean energy intake of 24 kcal/kg of body weight prior to the intervention. Following the nutrition education intervention, there was a significant increase in total energy, carbohydrate, and protein intake in combination with increased sports nutrition knowledge. There was a 9% increase in carbohydrate intake and a 18% increase in participants meeting recommended protein intake. As a result of nutrition education, participants were able to improve dietary intake and lower the risk of low EA. The individualized counseling provided by the Registered Dietitian confirmed to be beneficial for improved dietary intake, nutrition knowledge and application of performance principals within these athletes (Valliant 2012)

Rossi and colleagues (2017) examined how sports nutrition education influenced dietary intake, knowledge, body composition, and performance in NCAA Division I baseball players. A sports nutrition knowledge questionnaire was administered pre- and post-intervention along with assessment of nutrient intake and physical performance markers. The intervention group consisted of fifteen participants and were matched with non-intervention participants based on position. The intervention group received a 90 minute nutrition education presentation given by the lead investigator at the beginning of the intervention period which emphasized the importance of nutrition for baseball performance. Every three weeks following the initial session occurred with five players gathering at a time for 45 minutes to reinforce the nutrition education. Results from this study show an increase in nutritional knowledge and status in the sports nutrition education intervention group in comparison with the non-intervention group. Low EA was observed pre-intervention as energy intake was less than the requirement for this population. Post-intervention energy intake was significantly greater and improvements in the sports nutrition knowledge questionnaire from pre- to post- intervention were also present in the study. Therefore, this provides evidence that nutrition education can decrease the risk of low EA (Rossi 2017)

Hull and colleagues (2016) conducted a cross-sectional survey designed to assess dietary habits and nutrition practices in NCAA Division I athletes. Low energy availability was not observed in this population. 383 male and female student-athletes from 10 different sports participated and completed a survey consisting of a variety of questions on dietary habits and practices. Sports dietitians were employed at the institutions where these athletes were from and their primary aim was to provide nutrition education and counseling to improve athletic performance. Results from the survey show that 60% of athletes reported working with the sports dietitian. This group was more likely to have post-

workout nutrition options and less likely to consume fast food prior to practice or competition while on team trips compared to the group who did not meet with the dietitian. Lastly, the sports dietitian group had increased awareness of adjusting caloric intake and indicated off-season and in-season nutrition differed compared to the non-dietitian group. Overall, this study indicated that the benefit of using a sports dietitian as the primary source for nutrition education improved dietary habits among collegiate athletes (Hull 2016).

A study conducted by Day and colleagues (2015) assessed how nutrition education interventions changed knowledge and dietary behaviors in female collegiate athletes. This study consisted of 25 participants and assessment of body composition, 3-day diet recalls before and after nutrition education, and pre/post nutrition knowledge questionnaire was completed. Nutrition education provided by a registered dietitian or a dietetic student occurred once a week for 30 minutes over the course of six weeks. Results of this study showed an improvement in individual nutrition knowledge from pre- to post-nutrition education intervention. The recommendation for mean daily index of EA in this group is 45 kcals/kg of fat free mass (FFM)/day and participants in this study had a mean daily index of EA of 30.8 kcals/kg of FFM/day which is significantly lower. Although there was an increase in nutrition knowledge, this observation indicates that participants did not change their eating behaviors as a result of the intervention. Overall, nutrition education led to increased nutrition knowledge, however, prevalence of low EA and dietary intakes did not change (Day 2015).

Overall, encouraging nutrition education programs that emphasize on RED-S, healthy eating, energy availability and the risks of dieting and how these factors influence health and performance is critical. Nutrition education may be beneficial for improving dietary intake, nutrition knowledge, and optimizing athletic performance and preventing low EA and its consequences in college athletes.

Discussion

Summary of Findings

Overall, there are 14 studies that are included in this narrative review with 4 studies evaluating nutrition knowledge and dietary intake, 5 studies investigating nutritional knowledge of collegiate athletes, 3 studies evaluating how low EA affects athletic performance, and 3 studies investigating how nutrition education/knowledge influences athletic performance. The purpose of this narrative review is to evaluate the literature on low energy availability in college athletes and determine if nutrition education can improve athletic performance.

The prevalence of low EA appears in any athletic population and has been investigated within various sports affecting both male and female athletes. It has been suggested that low EA can have detrimental effects on an athlete which in turn may diminish athletic performance, however, there are few studies that have investigated this. Three studies examined the relationship between athletes with low EA and its effects on performance and injury. Results from these studies displayed negative effects on performance when an athlete exhibited low EA including decreased performance times, decline in bone health, impaired judgment, and decreased coordination (Ackerman 2019, Keay 2019, Vanheest 2014). Other studies have found that menstrual dysfunction that is associated with low EA results in increased bone stress injury risk which can impact training and competition (Logue 2020). Nutrient deficiencies, fatigue, and increased risk of infections and illnesses can occur in athletes who suffer from long-term low EA (Mountjoy 2014). In all, it is essential that athletes maintain proper nutrition to prevent low EA and optimize athletic performance.

Five studies investigated the relationship between collegiate athletes and nutritional knowledge. Two studies found that athletes were not meeting energy requirements needed for their sport putting them at risk for low EA (Jagim 2019, Magee 2020). Some athlete groups indicated fair nutrition knowledge but were not applying it (Hoogenboom 2009) while another group scored poorly on a nutrition knowledge questionnaire but indicated good dietary practices (Klein 2021). Overall, collegiate athletes lack the nutritional knowledge needed to make appropriate nutritional decisions based on their sport and to enhance athletic performance. Although athletes may be able to improve their nutrition knowledge, applying the concepts may be absent. The lack of nutritional knowledge in athletes increases their risk for RED-S and its sports performance consequences. Additionally, a cross-sectional study evaluated NCAA athletic trainers and their knowledge of RED-S and results showed only 33% were aware of the syndrome (Kroshus 2018). Not only is it important for athletes to be aware of nutritional recommendations, it is critical that members of the athletes multidisciplinary team (coaches, athletic trainers, etc.) are educated as well.

The evidence on how nutrition education or nutrition knowledge of an athlete influences athletic performance is limited. There are three studies that investigated the relationship between nutrition knowledge and athletic performance in collegiate athletes. All studies concluded that increased nutritional knowledge can result in enhancement of performance indicators (Folasire 2014, Rossi 2017, Hull 2017). Overall, it can be predicted that increased knowledge may improve low EA thus improving athletic performance.

Among the studies investigating nutrition knowledge and dietary intake, two studies concluded that nutrition education may improve dietary intake and knowledge in NCAA division I athletes. Athletes were less likely to consume fast food and were more aware of caloric intake compared to groups who did not receive nutrition education (Hull 2016). Improvements in total energy, carbohydrate, and protein intake as a result of nutrition education was observed (Vaillant 2012, Rossi 2017). Therefore, nutrition education may improve dietary intake in college athletes with low EA. However, one study found that nutrition education interventions increased nutritional knowledge but did not result in improvement in EA or dietary intake (Day 2015). Additional interventions and ways to address barriers may be warranted for groups that were unable to improve dietary intake with nutrition education interventions.

Four studies in this review indicated the use of a registered dietitian for nutrition education with the goal of improving athletic performance in athletes. Rossi et al found improvement in macronutrient consumption, improved body composition, and potential performance benefits when baseball players were provided nutrition education by a RD (Rossi 2017). Other studies showed improved energy and macronutrient intake, improved nutrition knowledge and dietary intake in comparison to those who did not have access to a RD (Valliant 2012, Hull 2016, Hull 2017). While there is often a lack of nutritional knowledge in collegiate athletes, a dietitian can fill this gap and provide nutrition interventions to improve health and performance in athletes.

Recommendations to address RED-S and low energy availability

To improve athletic performance, it is necessary that an athlete is well educated on sports nutrition guidelines to prevent RED-S and low EA. Encouraging nutrition education programs that emphasize on RED-S, healthy eating, energy availability and the risks of dieting and how these factors influence health and performance is critical. In addition, sports nutrition education interventions should involve not only the individual athlete, but as well as coaches, athletic trainers, physiologists, or foodservice staff in order to achieve optimal nutrition success for athletes. These members should not only think about performance aspects but keep an eye on athletes body weight and dietary behavior. Overall, nutrition education can be beneficial for improving dietary intake, nutrition knowledge, optimizing athletic performance and preventing low EA in athletes.

While nutrition education for coaches and athletic trainers are important, these individuals also play an important role in becoming aware of when an athlete may be at risk for RED-S. Early detection and screening of RED-S is critical in preventing long-term health and performance consequences. Annual

exams should consist of screening for RED-S especially if an athlete presents with disordered eating, weight loss, lack of normal growth, menstrual dysfunction, recurrent injuries and illnesses, and decreased performance (Mountjoy 2014). Currently, there are no guidelines or screening tools that are standardized for diagnosis or RED-S. The focal point in diagnosis of RED-S is identifying the presence and causes of low EA considering that is the main factor in the development of RED-S. Treatment of low EA should include an increase in energy intake, reduction of exercise or a combination of both (Mountjoy 2014). This would consist of gradual increase in energy intake which may include a supplement or introduction of a rest day in the training program. Treatment strategies for psychological factors should be initiated by a mental health professional that is knowledgeable in the management of disordered eating in athletes.

When attempting to prevent low EA, college athletes often experience barriers to nutrition education and proper fueling because of their busy lifestyles. Time, stress, cooking skills, financial constraints, psychological reasons and lack of adequate resources are all factors to consider when evaluating an athlete for low EA and discussing improvement methods. An athlete's health may also be influenced by their social environment including teammates and social media platforms (Wasserfurth 2020). These factors can result in poor dietary choices and in turn lead to improper fueling/recovery from sport, injury, and decreased athletic performance.

Conclusion

Further research is needed in evaluating how nutrition education can improve low EA and athletic performance in athletes. Having access to a registered dietitian as part of the multidisciplinary team for college athletes may improve nutrition knowledge and lower the risk for nutritional deficiencies. It is evident that low EA has health and performance consequences and nutrition interventions by a dietitian may improve these repercussions. Future research should investigate the relationship of having a dietitian as part of the athletic team and nutrition knowledge, behaviors, and athletic performance as well as injury risk and recovery in collegiate athletes.

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