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NUTRITIONAL PRACTICES ASSOCIATED WITH LOW ENERGY AVAILABILITY IN DIVISION I FEMALE SOCCER PLAYERS

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ABSTRACT

Background: Low dietary energy intake in relation to high exercise energy expenditure resulting in low energy availability (EA) has been observed in elite female soccer players. Short term studies manipulating dietary energy intake and exercise energy expenditure have shown that negative metabolic, reproductive, and bone related changes occur below an EA of 30 kcal/kg LBM. To date, no studies have examined the association between nutritional practices such as dietary carbohydrate and protein intake, energy density, and caloric distribution of dietary energy intake and levels of EA. **Objective:** The purpose of this study was to examine changes in energy and macronutrient consumption across the season and to evaluate dietary practices such as macronutrient and energy intake, energy density, and dietary energy distribution that may be associated with low energy availability in Division I female soccer players across a competitive season. **Methods:** Nineteen participants (18-21 years; VO_{2max}: 57.0±1.0 ml/kg/min) were studied during the pre, mid, and post season. **Results:** When grouped according to whether they had an EA above or below 30 kcal/kg LBM, the proportion of Division I female soccer players who did not meet the American College of Sports Medicine (ACSM) recommendations for dietary carbohydrate and protein intake was determined. The proportion of Division I female soccer players who did not meet ACSM carbohydrate recommendations significantly differed from the proportion of players who did meet the recommendations during the pre season, but not the mid season ($\chi^2 = 11.8$, $p = 0.01$). The proportion of Division I female soccer players who did not meet ACSM protein recommendations significantly differed from the proportion of players who did meet the recommendations during the mid season, but not the pre season. A lower energy density at lunch (1.2 ± 0.2

vs. 1.8 ± 0.1 kcal/g; $p = 0.034$) and dinner (0.8 ± 0.1 vs. 1.4 ± 0.1 kcal/g; $p = 0.004$) was observed in Division I female soccer players with low compared to higher energy availability during the pre and mid season, respectively. Compared to sport drinks, other drinks, and bars/gels/beans, food comprised the greatest proportion of total kilocalories consumed by Division I female soccer players with higher (79%) and low EA (84%) when pre and mid season phases were combined. Sport drinks, the next highest proportion of total kilocalories consumed, comprised 8.8% and 5.9% of total calories in higher EA and low EA players, respectively. **Conclusion**: Nutritional practices such as inadequate dietary carbohydrate and protein intake and low energy dense diets at particular meals i.e., lunch and dinner were associated with low EA in this sample of Division I female soccer players. Identifying such practices may be important in preventing low EA in elite female athletes.

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Chapter 1

Literature Review

Female Athlete Triad

In 1992, the American College of Sports Medicine (ACSM) published their first position stand on the Female Athlete triad which identified the Female Athlete Triad as the interrelationship between osteoporosis, menstrual dysfunction, and disordered eating (1). In 2007, the ACSM released an updated position stand (1) which now defines the Triad as the interrelationship between osteoporosis, menstrual dysfunction, and low energy availability (EA). Women who suffer from the Female Athlete Triad often exhibit or develop conditions such as eating disorders, functional hypothalamic amenorrhea, and osteoporosis where either alone or in combination pose significant health risks to exercising women (1, 4). EA was defined as the difference between dietary energy intake (EI) and exercise energy expenditure (EEE) (1) normalized to kilograms of lean body mass (LBM) (2). An EA below 30 kcal/kg LBM has been associated with negative metabolic, reproductive, and bone health outcomes (5, 6) in previously sedentary women under controlled laboratory conditions. In those who take part in exercise training, a number of atypical eating behaviors such as fasting, vomiting, and the use of laxatives, as well as any alterations to EEE and EI may result in conditions of low EA (1, 7).

In one cross-sectional study of female soccer players (7), 32% of soccer players reported a history of dieting behavior while 24% met the criteria for a clinical eating disorder. Such practices of energy restriction, excessive energy expenditure, a drive for thinness, and consuming a diet that is associated with low energy density can have negative effects on menstrual (8), nutritional (4) and bone status (9), as well as athletic performance (10) and EA (11). Energy availability, which is considered to be the underlying mechanism of the Female Athlete Triad, can have a negative effect on bone density and menstrual function through alterations in metabolic hormones and estrogen activity (1). This relationship is illustrated in **Figure 1-1.**

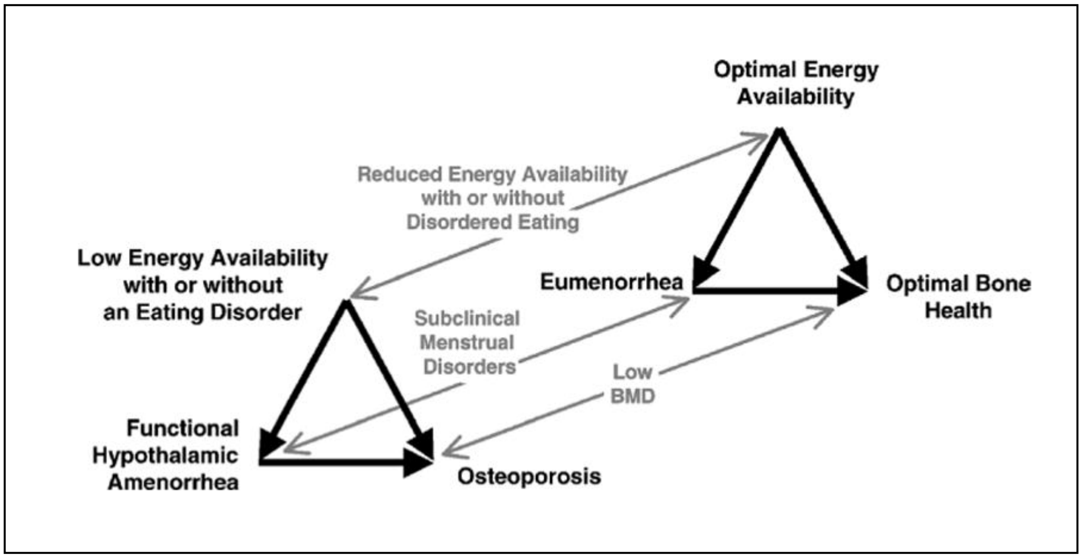


Figure 1-1 This figure, from the American College of Sports Medicine Position Stand: The Female Athlete Triad (1), depicts the interrelationship between the three components of the Triad: energy availability, menstrual function, and bone health.

Upwards of 66% of the female athlete population may experience amenorrhea while this is true for only 2-4% of the general population (12, 13). In a study by Hoch et al. which assessed the prevalence of the Female Athlete Triad in adolescent high school varsity athletes (n=80, age=16.53 ± 0.95 years old) and sedentary controls (n=80, age= 16.46 ± 1.17 years old), the prevalence of low EA (<45 kcal/kg LBM), menstrual dysfunction, and low bone mineral density was examined (14). A greater number of athletes presented with menstrual dysfunction while the control group had a greater number of individuals that met the criteria for low EA and bone mineral density (BMD) (14). One subject from each group possessed all three components of the Female Athlete Triad; the one individual in the athlete group was a soccer player (14).

Energy Availability

Energy Availability (EA) is defined as the difference between dietary energy intake (EI) and exercise energy expenditure (EEE) (1) normalized to kilograms of lean body mass (LBM) (2). EA represents the leftover energy after physical activity to perform functions such as cellular maintenance, thermoregulation, growth, and reproduction (15). Certain strategies such as increased physical activity or decreasing energy intake, or a combination of the two, can result in low EA conditions due to the interrelationship between these two factors. Energy availability, which is considered to be the underlying mechanism to the Triad, can have a negative effect on bone density, menstrual function, and metabolic hormone concentrations (1). EA at a level at or below 30 kcal/kg LBM has been associated with negative metabolic, reproductive, and bone health outcomes (5, 6). Low EA can have a detrimental effect on bone health as low EA conditions have been shown to increase markers of bone resorption and decrease makers of bone formation. This uncoupling between bone formation and resorption may consequently result in low bone mineral density through a number of hormonal cues (16).

In a study by Williams et al. (8), eight female cynomolgus monkeys were exposed to a seven-day/week regimen of increased exercise training through an exercise regimen consisting of running on a treadmill for a total of two hours/day. Energy intake (EI) was maintained by providing standardized meals consisting of 48% carbohydrates, 25% protein, and 5% fat by weight. While increasing exercise training and maintain EI, a total of eight monkeys developed exercise-induced amenorrhea while exhibiting abnormalities in luteinizing hormone (LH), follicle stimulating hormone (FSH), estradiol (E2), and progesterone (P4) concentrations (8). During the refeeding phase of the experiment, while continuing their exercise regimen, four of the eight monkeys were provided with extra calories (about 400 kcal/day). During this intervention, significant increases in total dietary energy intake, body weight, and LH, FSH, and E2 concentrations were observed. As a result of the refeeding, all four of the monkeys experienced restored menses. In fact, greater total energy intake was associated with a more rapid restoration of menses (8). These findings are paramount in the distinction that EEE, not other factors associated with physical activity, may play a pivotal role in the exercise induced effects on reproductive function. Furthermore, demonstrating the ability to restore reproductive function by means of increasing energy intake adds to the aforementioned conclusion that exercise induced amenorrhea may be an outcome of an energy deficiency and not the stressors of exhaustive exercise.

The impact of exercise energy expenditure on reproductive function has been identified in other reports (5, 6). In a comparison between female high school athletes and sedentary controls, one study (14) observed nearly paralleled occurrence of low EA (< 30 kcal/kg LBM). As shown through these findings, an uncoupling between EI and EEE may be present in the occurrence of low EA. The female athletes in this particular study exercised approximately 8 times more than the sedentary controls (8.66 hrs/week and 1.02 hrs/week) (14). Due to the similar occurrence of low EA, the athletes expended a greater number of kilocalories during exercise training in combination with inadequate dietary energy intake, possibly facilitating the observed low EA. Though the exact level of EA was not reported, the prevalence of low EA in female high school athletes was reported. It can be assumed that the female athletes in this study did not consume adequate calories in order to replenish depleted energy stores, a necessity in achieving and maintaining an optimal level of EA.

Energy Availability and Menstrual Function

Individuals with low EA may become susceptible to unfavorable physiological changes including menstrual dysfunction (8). A fluctuation in menstrual function lasting between 36-90 days is defined as oligomenorrhea. The complete cessation of menstrual function, amenorrhea, lasting longer than 90 days can also occur in instances of low energy availability (1). Post menarchal exercising females presenting menstrual dysfunction as a result of low energy availability is referred to as secondary amenorrhea (1). Primary amenorrhea is characterized as the delay in the age of menarche later than 15 years old (1). Though the term EA refers to the behavior of a subject and not the substrate availability for cellular metabolism, as EA is altered by an individual, so too may the physiological response (5).

The amenorrhea that female athletes demonstrate manifests due to the failure to provide sufficient energy to the hypothalamic arcuate nucleus (17). This in turn may cause dysfunction of the hypothalamic-pituitary-ovarian axis (18). Dysfunction in the hypothalamic arcuate nucleus and hypothalamic-pituitary-ovarian axis can cause miscues in a number of hormonal signals that play a vital role in proper menstrual function including gonadotropin, estrogen, and gonadotropin-releasing hormone (18). Such hindrances in these processes can be impact bone health and may place individuals at an increased risk of fractures and osteoporosis later on in life (1). Gonadotropin-releasing hormone is responsible for stimulating the secretion of luteinizing hormone (LH) and follicle-stimulating hormone (FSH) from the pituitary gland (18). Decreased secretion of these two hormones causes a down-regulation on ovarian function, negatively impacting estradiol production and thus bone formation (18). Abnormal LH pulsatility along with reductions in 3,3',5-triiodothyronine (T3), insulin, and insulin-like growth factor-I (IGF-I), as well as increases in cortisol and growth hormone (GH) were all observed during low EA conditions (19). These hormonal fluctuations are common among amenorrheic athletes who demonstrate decreases in plasma glucose, serum T3, IGF, and insulin, as well as increased concentrations of GH and cortisol (19).

By increasing EI and decreasing EEE, one study (20) was able to improve hormonal markers of menstrual and bone function over a period of 15 weeks in an amenorrheic endurance athlete. Improvements in serum LH concentrations of 148% above baseline to completion, as well as reductions in serum cortisol concentrations were observed. Such changes in LH pulsatility indicated the successful arrival at energy balance as well as possibly resumption of menstrual function. A similar study followed four amenorrheic endurance athletes for 20 weeks of a dietary and exercise intervention (21). The aim of this study was to assess the changes in energy status during an intervention involving increased energy intake and the addition of one rest day from normal training per week. Improvements in EI as well as energy balance were observed, as demonstrated by an increase in body weight in all four subjects. As shown through these findings, an uncoupling between EI and EEE may be present in the occurrence of low EA.

Energy Availability and Bone Health

Hormonal changes that are observed with low EA, as previously stated, are detrimental not only to reproductive function but also to bone health (5, 6). Ihle at al. reported the dose-response of habitual low energy availability on bone metabolism in a population of young sedentary, normally menstruating women while during the early follicular phase of two separate menstrual cycles (5, 6). Each subject participated in two, five-day study periods: one while at a normal EA (45 kcal/kg LBM) and another at low EA (30, 20, or 10 kcal/kg LBM/day). Levels of EA were met through supervised exercise and providing a diet of known caloric value. In order to assess bone formation, osteocalcin (OC) and serum type I procollagen carboxy-terminal propeptide (PICP) were measured. N-terminal telopeptide (NTX) was measured in order to assess bone resorption. For individuals that exhibited an EA of 10 kcal/kg LBM/day, NTX was significantly increased, suggesting an increase in bone demineralization. PICP and OC were significantly decreased in response to low EA conditions (6). These findings help support the claim that EA < 30 kcal/kg LBM is the threshold at which EA is considered "low" and negative hormonal changes may occur.

In one study of female adolescent runners (9), Barrack et al. designated athletes as normal bone turnover (NBT) or elevated bone turnover (EBT) depending on concentrations of bone-specific alkaline phosphatase (BAP) and C-telopeptides of type-I collagen (CTX). Athletes with elevated bone turnover exhibited elevated concentrations of BAP and CTX, indicating bone resorption, as well as lower serum estradiol when compared to the NBT runners. This observation goes along with the understanding that low estradiol concentrations, as a result of decreased estrogen production due to insufficiencies in follicle-stimulating hormone FSH and LH, can have a negative effect on bone mineral content (22). It was also noted that factors such as secondary amenorrhea, body mass index (BMI) <10% for age, and total energy intake <2000 kcal/day were greatly associated with menstrual dysfunction. The EBT group demonstrated a significantly lower total body, femoral neck, total hip, and lumbar spine BMC when compared to the NBT group. Similarly, in an observational study of female ballet dancers (n=15) when compared to controls (n=15), total dietary consumption and energy balance were both significantly lower in the dancers than in the controls. Despite the absence of a significant difference in BMD between the two groups, more dancers (6/15) reported irregular or absent menses and were also associated with a delayed menarche when compared to the controls (23).

Nutritional Strategies

Energy Density

Energy density has been shown to be an effective means of controlling EI by increasing the volume of food consumption while decreasing total energy intake (10, 24-26). Energy density is defined as the amount of energy in a given weight of food or beverage, and is commonly affected by the macronutrient composition and water content of the food or beverage (26). Consuming a lower energy density diet has great baring on weight maintenance and weight loss due to the potential decrease in energy consumption coupled with an increase in satiety due to increased food volume (27). Energy density will be important to assess in elite Division I female soccer payers due to its effectiveness in weight loss and weight management (28) and possibly on EA.

In one study of overweight men and women (28), subjects received either one serving of soup (one-soup group), two servings of soup (two-soup group), two servings of dry snack food (two-snack group), or no specific foods to consume (comparison group). At the completion of the 12 month study, it was observed that the two-soup group exhibited a greater total weight loss than the two-snack group. Though each group consumed foods (soup or snack) of similar energy content (<120 kcal/day) during the intervention, the energy densities differed. Despite significantly similar total energy intakes, this observed weight loss may have been as a result of insufficient diet recording, and in turn the inability to accurately measure the differences in total energy intake. This suggests that consuming a low energy dense diet may be beneficial for weight loss or maintenance. Another study that instructed obese participants (n=97) to consume a reduced fat diet (RF group) or a reduced fat diet plus increased intake of fruits and vegetables (RF+FV group) found similar results. Upon completion of the one year study, it was observed that despite similar fat consumption, the RF+FV group had a greater weight loss when compared to the RF group. This greater rate of weight loss may be related to the lower energy dense diet that was consumed.

To further illustrate the concept of energy density, a comparison between 100 grams of broccoli and 100 grams of almonds can be used as an example. One hundred grams (g) of broccoli (34 kcal) weighs the equivalent to 100 grams of almonds (595 kcal). Applying the concept of energy density to this example, the 100 grams of almonds is said to have a “greater” energy density than the 100 grams of broccoli due to the difference in energy content despite an identical weight. Consider the following mathematical equations in order to further illustrate this comparative example of energy density between broccoli and almonds:

Almonds
100 grams of almonds = 595 kcal
Energy Density = 595 kcal / 100 grams = 5.95

Broccoli
100 grams of broccoli = 34 kcal
Energy Density = 34 kcal / 100 grams = 0.34

Based on one report that the majority of female athletes tend to consume a lower total energy and carbohydrate intake when compared to male players (29), certain strategies of meal consumption and their effects on EA will be important to assess. Female athletes tend to consume approximately 30% fewer calories and carbohydrates then male athletes (29). Female athletes also tend to consume less food with respect to weight (29). These nutritional practices i.e., lower EI and energy density may consequently contribute to low EA conditions in female athletes. Without proper EI, low EA may result due to insufficiencies in replenishing previously depleted energy stores.

Restrictive Eating

A behavioral trait that has been associated with low EA is the conscious restriction of food intake (30, 31). In a previous study on female soccer player, 32% reported a history of dieting behavior and 24% met the criteria for a clinical eating disorder (1, 7). A subset of the eating disorder inventory (EDI), referred to as a drive for thinness (DT) (32) has been established as a valid means of assessing body eating behaviors. Taking into account that female athletes may consume a significantly lower total energy intake than male athletes (29), greater DT scores may indicate the occurrence of low EI. If this is so, the cognitive strategy of decreasing energy intake, as evidenced by a greater DT score, may have a negative impact on EA. This EA outcome may occur due to a decrease in energy consumption and an increase in EEE, placing female athletes at risk for the Female Athlete Triad (33).

Supplementation

The ACSM suggests minimal, if any, nutritional supplementation if an athlete's diet consists of adequate energy from a variety of food sources (2). Though student athletes are permitted to purchase many supplement products on their own, it is the policy of the National Collegiate Athletic Association (NCAA) to restrict the provision of certain nutritional supplements to student athletes (34). Creatine, ginseng, and protein powders are a few of the products on this restricted list (34). As long as protein concentrations do not exceed 30% of total calories, universities are allowed to supply the product to their student athletes (34). If an athlete relies heavily on university provided meals then such restrictions may prevent adequate nutritional intake. Due to the commonly reported inadequate energy intake by a variety of athletes (14, 23, 35-37), the provision and consumption of supplements may help increase EI and possibly prevent low EA.

In one cross-sectional study which assessed the nutritional intake of female adolescent soccer players, consumption of dietary supplements was uncommon (4). Of the 33 participants, only two consistently consumed a multivitamin supplement (calorie free) and one consumed a fatty-acid supplement (4). Similar findings were observed in a cross-sectional analysis of elite figure skaters (38). In this study, dietary supplementation made up about 9% of total calories from snacks (about 22% of total calories). Interestingly, while observing a low consumption of dietary supplements, Gibson et al. (4) reported inadequate EI to match EEE. Implementing certain nutritional strategies such as increased nutritional supplementation may improve EI to a comparable level to EEE. In this group of elite collegiate soccer players, adequate EI to match EEE may be difficult to achieve due to a possible lack of knowledge of food preparation, time constraints, or constant travel. Due to these possibilities, education may be necessary for all collegiate athletes, coaches, and trainers in order to optimize the general health and athletic performance of all athletes.

Nutritional Recommendations for Sports and Exercise

Energy Requirements

Due to the effects of training and competitive play on energy and nutrient reserves, recommendations for the general population, such as the dietary reference intakes (DRI), may not be suitable for elite athletes (39). It is important to achieve energy and macronutrient requirements to replenish potentially depleted stores, maintain body weight, grow and repair muscle tissue, and to maximize athletic performance (2). Individuals that consume an insufficient amount of energy and nutrients are at risk of poor athletic performance (16), abnormalities in reproductive and bone health (16), and loss of muscle and fat mass (2).

Calories are provided by four macronutrient sources: carbohydrate, protein, fat, and alcohol (40). For athletes, adequate dietary energy consumption is important for both health and athletic performance (1, 10). Though the importance of energy consumption is widely known, inadequate intake is commonly observed in a variety of athletes (14, 23, 35-37). Energy restriction, excessive energy expenditure, a drive for thinness, and consuming a diet that is associated with low energy density can have negative effects on menstrual (1), nutritional (1), and bone status (1) as well as athletic performance (10). ACSM recommendations for nutrition and athletic performance (2), the dietary reference intakes (3), and the acceptable macronutrient distribution ranges (3) are provided in **Table 1-1.**

Table 1-1 Nutritional recommendations from the American College of Sports Medicine (ACSM) (2), Dietary Reference Intake (DRI) (3), and Acceptable Macronutrient Distribution Range (AMDR) (3).

	ACSM Recommendations	DRI	AMDR
Carbohydrate	6-10 g/kg bw/day	130 g/day	10-35% total kcal
Protein	1.2-1.7 g/kg bw/day	46 g/day	45-65% total kcal
Fat	20-3% total kcal	-	20-35% total kcal

Carbohydrate Requirements

The sport of soccer is associated with intermittent high intensity activity that can greatly tax energy and nutrient reserves during both aerobic and anaerobic processes (4). Carbohydrate is one of the primary fuels for soccer players, thus placing added importance on its consumption (4). Dietary carbohydrates provide approximately 4 kcal/gram (40), glucose being the primary form. Normally, glucose in the body is converted through a series of enzymatic reactions to produce energy and pyruvate (40). Upon conversion to pyruvate, the metabolic pathway can be quite different depending upon the metabolic state of the individual (40). During aerobic conditions, pyruvate is transported to the mitochondria where it then goes a series of chemical reactions in the tricarboxylic acid (TCA) cycle, also known as the citric acid cycle or Krebs cycle (40). During the TCA cycle, pyruvate is metabolized to produce energy and acetyl CoA (40). During anaerobic conditions, pyruvate does not enter the TCA cycle and is converted to lactate through the action of the lactate dehydrogenase enzyme (40). This conversion of pyruvate occurs most often during periods of oxygen depletion such as during prolonged muscular exercise (40, 41). Due to the importance of carbohydrate in human physiology, athletes must be mindful of consuming proper amounts in order to optimize this vital energy source.

According to the ACSM position stand on Nutrition and Athletic Performance (2), carbohydrate consumption is of great importance to the athlete in order to maintain blood glucose concentrations as well as to replenish previously depleted glycogen stores. As recommended by the DRI (3), carbohydrate consumption should be between 45-65% of total dietary intake based on the Acceptable Macronutrient Distribution Range (AMDR) for adults >18 years old. Healthy Americans should be consuming approximately 130 g/day of carbohydrates in order to meet their daily requirement for general health (3). Due to an increase in nutritional needs (2), many athletes are suggested to exceed recommendations for the general population such as the DRI's.

There are a number of recommendations available for athletes regarding carbohydrate consumption. The ACSM recommends that athletes consume enough carbohydrate to replenish depleted glucose as well as to replace muscle glycogen (2). The recommendation set forth by the ACSM is to consume 6-10 g/kg body weight/day while taking into consideration the athlete's exercise energy expenditure, sex, and a number of other factors (2). Another source recommended 5-7 g/kg body weight/day for adult soccer in order to meet exercise energy expenditure (42). Despite these recommendations, it was observed in one study (4) of junior elite female soccer players that total carbohydrate consumption was approximately 5.0 ± 1.6 g/kg body weight/day, just shy of the ACSM recommendations. In this study, 17 athletes (51%) did not achieved the goal of >5 g/kg body weight/day from carbohydrate. Such observations are important because it demonstrates that carbohydrate consumption may be inadequate in athletes, as may be other nutrients.

Protein Requirements

Protein has a number of functions for physically active persons and is one of the four macronutrients that can provide dietary energy upon consumption (4 kcal/gram) (41). Proteins will be used as a source of energy during catabolic processes, provide the substrates for hair, bone, tendon, ligament, and red blood cell growth, and will provide the amino acids necessary for muscle tissue synthesis and maintenance (41). While it is common for athletes to over-consume protein, as great as 20% may consume below the recommendation (43). It is suggested by the recommended dietary allowance (44) to consume 0.8 g/kg body weight (bw)/day. Approximately 10-35% of the total dietary intake of adults >18 years old should be provided by protein (3).

Along with the DRI, there are a number of other recommendations which suggest increased protein needs of 1.6 g/kg bw due to the physiological demands of exercise (2, 45). The ACSM recommends 1.2-1.7 g/kg bw protein/day for athletes (2). While assessing a population of 33 adolescent female soccer players (mean=15.7 ± 0.7) during the competitive season (4), dietary intake was compared to the DRI and recommendations for athletes (42, 46). These recommendations suggest consuming approximately 1.2 g/kg bw protein per day (46). The majority of subjects consumed less than the recommended 1.2 g/kg body weight, potentially decreasing their ability to synthesize and repair muscle tissue. Another study (47), while assessing the pre and post season periods of NCAA division I female soccer players (n=13), there was a significant difference in the average protein consumption between the pre and post season periods. Protein consumption for the pre and post season was 1.4 ± .3 and 0.96 ± 0.3 g/kg bw, respectively. These levels of consumption during the pre season (average= 1.4 ± .3 g/kg bw) exceed the recommendations expressed through the DRI as well as those for athletic performance (47). Such findings indicate that protein intake may not be of particular concern due to the commonly reported excessive consumption. However, for athletes that do not meet general recommendations for protein intake may be at an increased risk for low EA due to the energy content that may be associated with high protein foods.

Fat Requirements

In terms of kcal/gram, fat provides the most energy of all macronutrients: nine kcal/gram (40). Though dietary fat may have a generally “unhealthy” public perception, there are a number of functions that fat provides that are vital to human health. Fat serves as a tremendous source of energy and essential fatty acids, and provides a number of essential fat soluble vitamins such as vitamins A, D, E, and K (2). The Acceptable Macronutrient Distribution Range (AMDR) recommends 20-35% for adults >18 years old (3). In order to prevent dangerously low high density lipoprotein (HDL) cholesterol concentrations, fat consumption should be > 20% of total calories (3). For athletes, there are a number of other recommendations which suggest increased dietary fat needs due to the physiological demands of exercise (2, 45). Despite these reports, the ACSM (2) recommends identical levels of consumption to the AMDR (3): 20-35% of total calories. The ACSM also refutes the practice of high fat diets and diets that provide <20% of total calories from fat as these levels are not beneficial to athletic performance (2). Due to the high energy content (9 kcal/gram) that dietary fat provides, inadequate consumption of fats may hinder EI even if replaced by another macronutrient, i.e. carbohydrate or protein. For example, if an individual were to replace 5 grams of fat for 5 grams of carbohydrate, i.e. decrease dietary energy density, total energy intake will decrease from 45 kcal to 20 kcal: a difference of 25 kcal. In circumstances of greater proportion, such decreases in fat consumption can greatly impact EI and possibly EA.

Chapter 2

Introduction

The Female Athlete Triad is a syndrome of three interrelated conditions: low energy availability, menstrual disturbances, and low bone mineral density (1). These conditions either alone or in combination pose significant health risks to exercising females (1, 4). Menstrual disturbances (19, 23), lower resting metabolic rate (RMR) (23), low bone mineral density (BMD) (9), and stress fractures (48) have been reported in energy deficient exercising females. Females participating in leanness and aesthetic sports are typically at the greatest risk for the Female Athlete Triad (1). A recent report revealed an unexpected high prevalence of dieting, eating disorders, and menstrual disturbances in female soccer players placing them at risk for the Female Athlete Triad (7). In one study examining the prevalence of the Female Athlete Triad in high school female athletes participating in a range of sports, the one participant who presented with all three components of the Triad was a soccer player (14). Energy availability, which is considered to be the underlying mechanism of the Female Athlete Triad, can negatively impact bone mineral density and menstrual function through alterations in metabolic hormones and estrogen activity (1).

Energy availability (EA) has been defined by one investigator as the difference between dietary energy intake (EI) and exercise energy expenditure (EEE) normalized to kilograms of lean body mass (LBM) (EA=EI-EEE/kg LBM) (5). This variable represents the amount of EI remaining after exercise training for all other metabolic processes such as reproduction, thermoregulation, cellular maintenance, locomotion, and growth [48-49]. Conditions of low EA (<30 kcal/kg LBM) have been shown to suppress metabolic hormones [4, 50-52] and cause unfavorable alterations in bone markers (6). In addition, reductions in luteinizing hormone (LH) pulsatility have been observed below an EA of 30 kcal/kg LBM in previously sedentary women during short-term manipulations of EI and EEE in a controlled laboratory setting (5). In the first study to examine changes in EA across a season in elite athletes in any sport, Reed et al. (in review) demonstrated that a concerning proportion of Division I female soccer players are at risk of low EA. Several investigators have also documented lower EI (4) in relation to high EEE (49) in elite female soccer players. It is therefore important to examine the nutritional practices that may contribute to low EI and consequently low EA.

Nutritional recommendations for the general population, such as the dietary reference intakes (DRI), may not be sufficient for elite athletes who engage in large volumes of exercise training (39). Increased carbohydrate and protein recommendations for athletes are necessary in order to replenish glycogen stores, synthesize muscle tissue, maintain body weight, and maximize the effects of training (2). Gibson et al. (4) observed low EI (2,079 kcal/d) and inadequate carbohydrate consumption by 51% when compared to high energy expenditure (2,546 kcal/d) in elite female junior soccer players. A linear relationship between protein consumption (g/kg bw/d) and dietary energy intake has been reported in elite female athletes (50) such that low dietary protein intake is associated with low EI. These findings indicate that inadequacies in macronutrient consumption, in particular dietary carbohydrate and protein intake, may result in lower EI and possibly lower EA in athletes who engage in large volumes of exercise training.

Consuming a low energy dense diet may be a strategy of exercising women to reduce dietary energy intake. Energy density represents the amount of energy in a specific weight of a particular food or beverage and is generally presented as kilocalories per gram consumed (kcal/g) (26, 28). Reed et al. observed a lower energy dense diet and lower dietary energy intake in recreational and elite exercising females with severe menstrual disturbances (11). No studies to date have examined the relation between energy density and EA. As female athletes tend to consume lower total dietary energy intakes when compared to their male counterparts and, under ad libidum conditions, may consume a constant weight of food as opposed to dietary energy intake, it is therefore important to examine the relation between energy density and EA as lower energy density may consequently lead to low EA conditions (10, 51)

Athletes may consume sport supplements to improve health, build muscle, improve athletic performance, or increase dietary energy intake (52). Though no studies to date have assessed the nutritional strategies to optimize EA in elite female soccer players, a few have analyzed the supplementation practices of elite athletes (52, 53). Sports drinks have been identified as the most commonly used supplement while sports bars, energy drinks, and protein powders, though less commonly used, were also reported (52, 53). The most commonly reported reason for consuming supplements was to increase dietary energy intake (52). Similarly, Lun et al. reported “increased energy” as the main reason for use by participants that take part in “intermittent” sport, i.e. soccer, the most represented sport in this study (n=17.8%) (53). If the common reason for supplement use is to increase dietary energy intake, participants who do not consume supplements but engage in large volumes of exercise training may be at greater risk of inadequate energy intake and possibly low EA.

The purpose of this study was to test the following hypotheses: 1) when grouped according to EA, a greater proportion of Division I female soccer players in the low EA group (<30 kcal/kg LBM) vs. the high EA group (≥30 kcal/kg LBM) will fail to meet the ACSM carbohydrate (6-10 g/kg body weight) and protein (1.2-1.7 g/kg body weight) recommendations, 2) Division I female soccer players with low EA (<30 kcal/kg LBM) will consume a diet that is lower in energy density (kcal/g) at particular meals than Division I female soccer players with higher EA (≥30 kcal/kg LBM), and 3) Division I female soccer players with low EA (< 30 kcal/kg LBM) will consume a smaller percentage (%) of total dietary energy intake from sport supplements than Division I female soccer players with higher EA (≥30 kcal/kg LBM).

Chapter 3

Materials and Methods

Study Design

During the pre (3 consecutive days in August), mid (3 consecutive days in October), and post (3 consecutive days in November) season periods, repeated measures of anthropometrics, demographics, aerobic fitness, EA, EI, EEE, and body composition, were obtained.

Participants

Members of a National Collegiate Athletic Association (NCAA) Division I female soccer team at a university located in the northeastern United States participated in this study. During an initial visit, study details and participation requirements were explained, and written informed consent was obtained. The study was approved by the university's Institutional Review Board for Research with Human Participants. To be included in the study, participants were required to be current members of the university's Division I female soccer team. Twenty-five participants signed the informed consent. Two participants later withdrew due to time commitment, two from lack of interest, and two due to injuries. A total of 19 participants completed all phases of the study.

Anthropometrics

Total body weight was measured by a digital scale in the laboratory to the nearest 0.01 kg wearing t-shirt and gym shorts after an overnight fast between 0700 and 1000 during the pre, mid, and post season. Height was measured to the nearest 1.0 cm without shoes during the pre season. Body mass index was calculated as a ratio of weight to height (kg/m^2). Body composition, including percent body fat, fat mass, and LBM was analyzed during the pre, mid, and post season by a certified technician using dual-energy x-ray absorptiometry (DXA). The participants were scanned on a GE Lunar iDXA scanner (General Electric Lunar Corporation, Madison, WI, enCORE 2008 software version 12.10.113).

Exercise Testing

Measurement of maximal aerobic capacity (VO_{2max}) was performed during the pre and post season on a treadmill using indirect calorimetry and the modified Åstrand protocol (54). Gas exchange was continuously monitored by a breath-by-breath system (SensorMedics Vmax metabolic cart, Yorba Linda, Calif., USA). VO_{2max} was achieved if 3 of the 4 following criteria were obtained: (1) attainment of age-predicted maximal heart rate (208-(0.7*age); (2) respiratory exchange ratio ≥ 1.1; (3) plateau in oxygen consumption despite an increase in exercise workload; (4) attainment of a rating of perceived exercise score ≥ 18.

Energy Availability

Energy availability (EA) is defined as energy intake (EI) minus exercise energy expenditure (EEE) relative to kilograms of lean body mass (kcal/kg LBM) (5) and calculated during the pre, mid, and post season. Measures of EI and EEE were performed for the same 3 consecutive days during the pre, mid, and post seasons. Measures of LBM were obtained during one of the 3 consecutive days during all time points. EA was assessed on typical training days during the pre (3 practice days), mid (2 practice and 1 home game day), and post seasons (3 non practice/game days).

Dietary Energy Intake

Total EI was assessed from 3-day diet logs during the pre, mid, and post season. A member of the research team with graduate training in sports nutrition instructed participants how to accurately record all foods and beverages consumed and provided participants with a food amounts packet. The packet contained diagrams illustrating container sizes, cuts of meat, and various circles and squares which are used when estimating portion sizes for foods. Participants were encouraged to use these scaled diagrams as a guide for describing dimensions and sizes. Also included in the packet was a sample page of an accurately completed diet record provided as a reference. Participants were asked to record all food and beverages consumed for 3 consecutive days, including time of day, location, and meal type i.e. breakfast. Diet logs were checked for completeness and accuracy when returned. Nutrient data from the 3-day logs were coded and analyzed using the Nutritionist Pro Diet Analysis software (Axxya Systems, Stafford, TX software version 4.5) and used to estimate dietary energy, carbohydrate, protein, and fat intake. The average EI from the 3-day diet logs provided the EI to compute EA during the pre, mid, and post season.

ACSM Recommendations: Nutrition and Athletic Performance

The average dietary carbohydrate, protein, and fat intake of Division I female soccer players during the pre and mid season was compared to the American College of Sports Medicine (ACSM) Position Stand: Nutrition and Athletic Performance (2). The ACSM recommends that athletes consume 6-10 g/kg body weight (bw)/day of carbohydrate, 1.2-1.7 g/kg bw/day of protein, and 20-35% total kcal/day from fat. If the average dietary carbohydrate, protein, and fat intake of Division I female soccer players were within the ranges provided by the ACSM, then they were considered to have “met” the recommendations. If the average carbohydrate, protein, and fat intake of Division I female soccer players was not within the range provided by the ACSM (2), then the level of consumption was considered to have “not met” the range.

Nutritional Strategies

Energy Density Calculations

Energy density was defined as the number of kilocalories per gram of foods or beverages consumed. The first meal of the day was coded as breakfast, second as lunch, third as dinner, and fourth as supper. Foods and beverages were considered part of one eating occasion if foods and beverages were consumed within a 30 minute period in the same location (55). Energy density was calculated as total kilocalories (kcal) divided by the total weight of all foods and beverages (g) consumed at breakfast, lunch, and dinner during the pre and mid season using the 3-day diet logs. Energy density was only calculated for breakfast, lunch, and dinner due to the small sample size of the other eating occasions. The energy density of Division I female soccer players with higher EA ($\geq$30 kcal/kg LBM) and low EA (<30 kcal/kg LBM) were compared at breakfast, lunch, and dinner during the pre and mid season.

Distribution of Dietary Energy Intake

The distribution of total dietary energy intake was calculated by categorizing all energy containing foods and beverages into one of four categories: sport drinks, other drinks, bars/beans/gels, and food. The “sport drink” category consisted of beverages such as Gatorade, Powerade, Monster, etc. The “other drinks” category consisted of beverages such as coffee with cream, milk, iced team, soda, etc. The “bars/beans/gels” category consisted of foods such as Cliff Bars and Snickers Marathon Bars. The “food” category consisted of all other food products such as pasta, bread, fruit, etc. For each of the three days that nutritional intake was assessed during the pre and mid season, the average dietary energy intake from these 6 days of diet logs for the above mentioned categories was calculated. This calculation represents an average of the pre and mid season dietary energy intake. The dietary energy intake for each category was then divided by the average total daily energy intake which provided the percentage of calories from each of the four categories. The calculation below provides an example of how the percentage of total kilocalories from the “sport drink” category was calculated:

Total average dietary intake/day ("sport drink" category) = 265.3 kcal/day
Average total dietary intake/day = 2733.7 kcal/day
Percentage of kilocalories from "sport drinks" = 265.3/3017.1 kcal x 100% = 8.8% of total kcal

Exercise Energy Expenditure

Three methods were used to determine EEE: 1) Polar Team^2 software, 2) Polar FT4 heart rate monitors, and 3) purposeful exercise logs. Energy expended during team training sessions such as soccer practice, soccer games, and weight lifting, as well as during non-team training sessions, was measured using the OwnCal feature of the Polar Team^2 software (Polar Electro Oy, Kempele, Finland) (56). The OwnCal feature has been validated for the use in calculating EEE from heart rate (56). The compendium of physical activities was used to determine the appropriate metabolic equivalent (MET) level for the exercise performed for the few (<10%) purposeful exercise sessions in which participants were unable to wear the Polar heart rate monitors (57). Participants recorded the duration, mode, and intensity of all purposeful exercise sessions on physical activity logs for 3 consecutive days during the pre, mid, and post season. This information was used to select the appropriate MET level. To calculate the energy expended during these exercise sessions, the following equation was used:

EEE = duration (minutes) x ((METs x 3.5 x weight (kg))/200) (58).

Statistical Analysis

Before statistical analyses were performed, all variables were tested for outliers. Extreme outliers were not included in our analysis. Analysis of variance (59) was performed to examine the changes in across the pre, mid, and post season. Chi-square analysis was performed to examine the distribution of participants meeting the ACSM recommendations for carbohydrate and protein consumption above and below an EA of 30 kcal/kg LBM. Independent t-tests were performed to compare differences between groups. All data are reported as mean ± SEM, and $p \leq 0.05$ was considered statistically significant. All data were analyzed with SPSS for Windows (version 18; Chicago, Ill., USA).

Chapter 4

Results

Participant Characteristics and Demographics

Descriptive data for all Division I female soccer players during the pre, mid, and post season are shown in **Table 4-1**. No differences in weight, body mass index (BMI), maximal oxygen uptake (VO_{2max}), percent body fat (%BF), fat mass (FM), and lean body mass (LBM) were detected across the season (p>0.05). Participants exercised an average of 135 ± 3, 101 ± 1, and 18 ± 1 minutes per day during the pre, mid, and post season, respectively. Average exercise heart rates were 131 ± 2 and 132 ± 2 beats/minute (bpm) during the pre and mid season, respectively.

Table 4-1 Demographics and anthropometrics of Division I female soccer players across the season (n=19).

	Pre Season	Mid Season	Post Season	P Value
Age (year)	19.23 ± 0.3	-	-	-
Height (cm)	165.6 ± 1.2	-	-	-
Weight (kg)	60.6 ± 1.4	61.3 ± 1.4	61.0 ± 1.4	P=0.146
BMI (kg/m^2)	22.2 ± 0.3	22.3 ± 0.3	22.2 ± 0.3	P=0.165
VO_2 max (ml/kg/min)	57.0 ± 1.0	-	56.8 ± 1.3	P=0.344
Body fat (%)	22.5 ± 1.1	22.9 ± 1.1	22.6 ± 1.1	P=0.253
Fat mass (kg)	13.2 ± 0.9	13.6 ± 0.9	13.3 ± 0.9	P=0.162
Lean body mass (kg)	44.6 ± 0.7	44.9 ± 0.7	44.9 ± 0.7	P=0.376

Values are shown as mean ± SEM.
*, $p < 0.05$

Daily energy and macronutrient intake

Energy availability and daily energy and macronutrient intake of Division I female soccer players during the pre, mid, and post season are shown in **Table 4-2**. Repeated measures ANOVA showed a change in EA over time (time effect $F = 11.6$, $p = 0.017$) demonstrating a lower mid than post season EA. Repeated measures ANOVA revealed a change in dietary energy intake (kcal/d) over time (time effect $F = 8.7$, $p = 0.001$) demonstrating a lower mid ($p = 0.008$) and post ($p = 0.002$) than pre season dietary energy intake (kcal/d). Exercise energy expenditure decreased over time (time effect $F = 20.945$, $p <0.001$) showing a lower mid ($p = 0.024$) and post ($p = 0.001$) than pre season. No significant changes in lean body mass were demonstrated across the season.

Table 4-2 Energy availability and daily energy and macronutrient intake of Division I female soccer players across the season (n=19)

	Pre Season n=19	Mid Season n=15	Post Season n=17
Energy Availability (EA)			
EA (kcal/kg LBM)	38.9 ± 5.1	31.5 ± 3.7 [b]	42.7 ± 3.4
EI (kcal/d)	2794.4 ± 903.0	2207.9 ± 156.1 [a]	2161.0 ± 554.1 [a]
EEE (kcal/d)	1030.2 ± 282.9	805.6 ± 115.9 [a]	562.2 ± 391.5 [c]
LBM (kg)	44.6 ± 0.7	44.9 ± 0.7	44.9 ± 0.7
Energy intake (EI)			
EI ($g \cdot d^{-1}$)	3902.1 ± 1407.0	2705.1 ± 338.0 [a]	2188.2 ± 1014.7 [a]
Carbohydrate (CHO)			
CHO (kcal/d)	1568.7 ± 455.8	1169.8 ± 111.2 [a]	1088.3 ± 301.2 [a]
CHO ($g \cdot d^{-1}$)	392.2 ± 113.9	292.4 ± 27.8 [a]	272.1 ± 75.3 [a]
CHO (g/kg bw)	6.5 ± 2.2	4.9 ± 0.5 [a]	4.5 ± 1.4 [a]
CHO (% of kcal)	56.7 ± 8.6	52.4 ± 2.7	50.5 ± 9.4 [a]
Protein			
Protein (kcal/d)	415.9 ± 154.6	364.9 ± 25.8	336.4 ± 122.1 [a]
Protein ($g \cdot d^{-1}$)	104.0 ±38.6	91.2 ± 6.4	84.1 ± 30.5 [a]
Protein (g/kg bw)	1.7 ± 0.7	1.3 ± 0.1	1.4 ± 0.5 [a]
Protein (% of kcal)	14.7 ± 2.4	16.7 ± 0.8	15.5 ± 4.3
Fat			
Fat (kcal/d)	837.7 ± 404.0	697.7 ± 71.0	693.0 ± 261.9
Fat ($g \cdot d^{-1}$)	93.1 ± 44.9	77.5 ± 7.9	77.0 ± 29.1
Fat (g/kg bw)	1.6 ± 0.8	1.3 ± 0.2	1.2 ± 0.5
Fat (% of kcal)	28.6 ± 6.9	31.0 ± 2.3	30.9 ± 7.8

Values are mean ± SEM

[a], $p < 0.05$ vs. pre season

[b], $p < 0.05$ vs. post season

[c], $p < 0.05$ vs. pre and mid season

EA, Energy Availability; EI, Energy Intake; EEE, Exercise Energy Expenditure; LBM, Lean Body Mass

Repeated measures ANOVA revealed a change in dietary energy intake (g/d) over time (time effect F = 1 8.6, p < 0.001) demonstrating a lower mid (p < 0.001) and post (p < 0.001) than pre season dietary energy intake (g/d).

Repeated measures ANOVA revealed a change in dietary carbohydrate intake (kcal/d) over time (time effect F = 13.2, p < 0.001) demonstrating a lower mid (p = 0.002) and post (p = 0.002) than pre season dietary carbohydrate intake (kcal/d). Repeated measures ANOVA revealed a change in dietary carbohydrate intake (g/d) over time (time effect F = 13.2, p < 0.001) demonstrating a lower mid (p = 0.002) and post (p = 0.002) than pre season dietary carbohydrate intake (g/d). Repeated measures ANOVA revealed a change in dietary carbohydrate intake (g/kg bw) over time (time effect F = 13.5, p < 0.001) demonstrating a lower mid (p = 0.003) and post (p = 0.002) than pre season dietary carbohydrate intake (g/kg bw). Repeated measures ANOVA revealed a change in dietary carbohydrate intake (% of kcal) over time (time effect F = 3.4, p = 0.047) demonstrating a post (p = 0.021) than pre season dietary carbohydrate intake (% of kcal).

Repeated measures ANOVA revealed a change in dietary protein intake (kcal/d) over time (time effect F = 4.5, p = 0.020) demonstrating a lower post (p = 0.041) than pre season dietary protein intake (kcal/day). Repeated measures ANOVA revealed a change in dietary protein intake (g/d) over time (time effect F = 4.5, p = 0.020) demonstrating a lower post (p = 0.041) than pre season dietary protein intake (g/day). Repeated measures ANOVA revealed a change in dietary protein intake (g/kg bw) over time (time effect F = 4.8, p = 0.016) demonstrating a lower post (p = 0.039) than pre season dietary protein intake (g/kg bw).

No significant differences in dietary protein intake (% of kcal) and dietary fat intake (kcal/d, g/d, g/kg bw, and % of kcal) were observed across the season ($p > 0.05$).

Energy availability

EA and its components in this sample of Division I female soccer players have been previously reported by Reed et al. (in review). Low EA (<30 kcal/kg LBM) was observed in 9 of 19 (47%) during the preseason, in 6 of 15 (40%) during the midseason, and in 2 of 17 (12%) of participants during the post-season.

ACSM Recommendations: Nutrition and Athletic Performance

The number of Division I female soccer players not meeting the American College of Sports Medicine recommendations for nutrition and athletic performance (2) when grouped according to low and higher EA during the pre and mid season are shown in **Table 4-3.** The proportion of Division I female soccer players who did not meet the ACSM recommendations for dietary carbohydrate intake significantly differed from the proportion of Division I female soccer players who did meet the recommendations during the pre season when grouped according to whether they had an EA above or below 30 kcal/kg LBM ($\chi^2 = 11.8$, $p = 0.01$). The proportion of Division I female soccer players who did not meet the ACSM recommendations for dietary protein intake did not differ from the proportion of Division I female soccer players who did meet the recommendations during the pre season when grouped according to whether they had an EA above or below 30 kcal/kg LBM ($\chi^2 = 1.6$, $p = 0.213$).

Table 4-3 Number of Division I female soccer players not meeting the recommendations for nutrition and athletic performance by the American College of Sports Medicine (ACSM) (2).

	Pre Season		Mid Season	
	EA ≤ 30 kcal/kg LBM n = 9	EA > 30 kcal/kg LBM n = 10	EA ≤ 30 kcal/kg LBM n = 6	EA > 30 kcal/kg LBM n = 9
Carbohydrate 6-10 g/kg body weight	8/19 (42.1%)	1/19 (5.3%)	6/15 (40.0%)	5/15 (33.3%)
Protein 1.2-1.7 g/kg body weight)	3/15 (20%)	1/15 (6.7%)	3/15 (20%)	0/15 (0.0%)

The proportion of Division I female soccer players who did not meet the ACSM recommendations for carbohydrate intake did not differ from the proportion of Division I female soccer players who did meet the recommendations during the mid season when grouped according to whether they had an EA above or below 30 kcal/kg LBM (χ^2= 3.6, p = 0.057). The proportion of Division I female soccer players who did not meet the ACSM recommendations for protein intake significantly differed from the proportion of Division I female soccer players who did meet the recommendations during the mid season when grouped according to whether they had an EA above or below 30 kcal/kg LBM (χ^2= 5.6, p = 0.018).

Due to the small number of participants (n = 2) with low EA (<30 kcal/kg LBM) during the post season, statistical analyses regarding differences in ACSM nutritional recommendations between participants above and below an EA of 30 kcal/kg LBM were not performed.

Nutritional Strategies

Energy Density

The energy density of Division I female soccer players of the three main eating occasions, i.e. breakfast, lunch, and dinner, is presented in **Figure 4-1.** A lower energy density at lunch (1.2 ± 0.2 vs. 1.8 ± 0.1 kcal/g; $p = 0.034$) was observed in participants with low compared to higher EA during the pre season (**Figure 4-1A**). A lower energy density at dinner (0.8 ± 0.1 vs. 1.4 ± 0.1 kcal/g; $p = 0.004$) was observed in participants with low compared to higher EA during the mid season (**Figure 4-1B**). Due to the small number of participants ($n = 2$) with low EA (<30 kcal/kg LBM) during the post season, statistical analyses regarding differences in energy density of particular eating occasions between participants above and below an EA of 30 kcal/kg LBM were not performed.

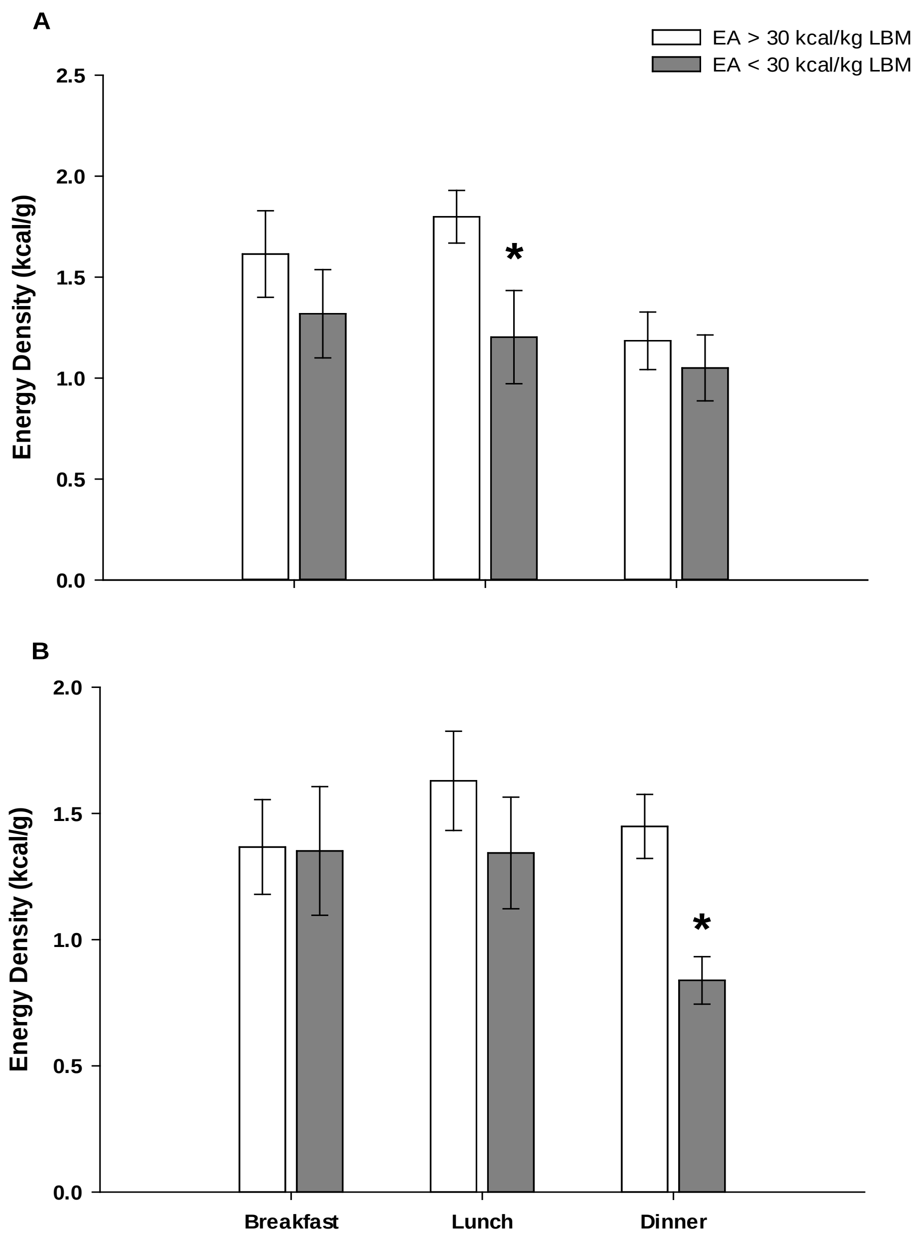
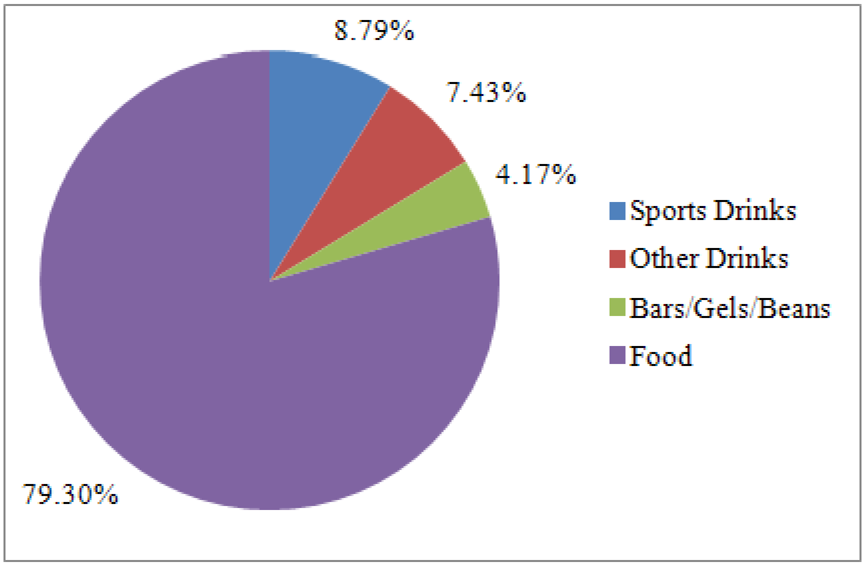


Figure 4-1. Bar graphs representing energy density of Division I female soccer players at breakfast, lunch, and dinner during the pre season (A) and mid season (B). Open bars represent energy availability $\geq$ 30 kcal/kg LBM. Solid bars represent the energy availability < 30 kcal/kg LBM. Data are expressed as mean ± SEM. *,P < 0.05 versus energy availability $\geq$30 kcal/kg LBM.

Distribution of Dietary Energy Intake

The proportion of kilocalories from sports drinks, other drinks, bars/gels/beans, and food of Division I female soccer players is presented in **Figure 4-2**. when pre and mid season values are combined **.** Food comprised the greatest proportion (79%) of total kilocalories consumed for Division I female soccer players with higher EA (**Figure 4-2 A**). Food also comprised the greatest proportion (84%) of total kilocalories consumed for Division I female soccer players with low EA (**Figure 4-2 B**). No significant difference in the proportion of kilocalories from sports drinks, other drinks, bars/gels/beans, or food were observed among Division I female soccer players when grouped according to whether they had an EA above or below 30 kcal/kg LBM ($p>0.05$).

A EA ≥30 kcal/kg LBM



B EA <30 kcal/kg LBM

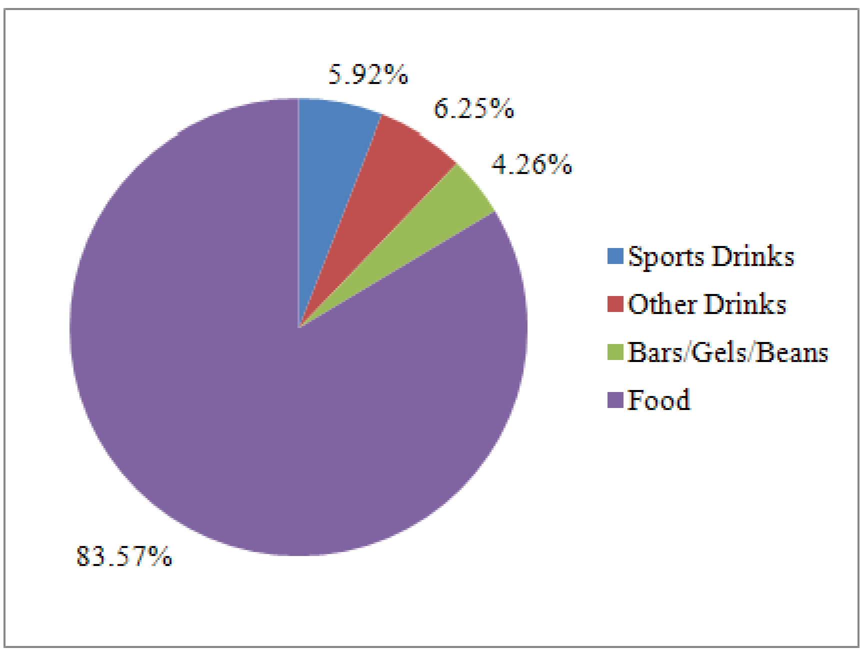


Figure 4-2 The proportion of kilocalories from sports drinks, other drinks, bars/gels/beans, and food of Division I female soccer players with higher EA (≥30 kcal/kg LBM) (A) and low EA (< 30 kcal/kg LBM) (B).

Chapter 5

Discussion

This study was the first to examine the dietary energy intake of Division I female soccer players at several time points across the competitive season and nutritional practices that may be associated with low EA. The specific aims of this study included examining the proportion of Division I female soccer players not meeting American College of Sports Medicine (ACSM) recommendations for carbohydrate and protein consumption for nutrition and athletic performance (2), the energy density of particular meals, and distribution of dietary energy intake in relation to levels of EA. As this population of athletes that has not been extensively studied, insight into the dietary habits of these elite athletes will help advance the field of nutrition and exercise science pertinent to elite female soccer players.

Division I female soccer players with low EA were observed to have an increased likelihood of not meeting the ACSM recommendations for carbohydrate consumption (6-10 g/kg body weight/day), an important contribution of the current study (2). Due to the intermittent high intensity that soccer is associated with (4), carbohydrate is a primary fuel source for these athletes. Gibson et al. (4), observed that approximately 51% of female junior elite soccer players did not meet recommendations for carbohydrate consumption (5 g/kg per day). Similar findings of inadequate carbohydrate consumption were observed in two other cross-sectional studies, of Division I female soccer players (47) and another in international male amputee soccer players (60). Gibson et al. noted that mean estimated energy expenditure was significantly greater than mean daily EI which suggests these soccer players may have experienced low EA conditions (4). Inadequate carbohydrate intake in elite female soccer players may place these athletes at an increased risk of low EA in the presence of high EEE through and uncoupling between EEE and EI. In one study testing the uncoupling between EI and EEE, an acute energy deficiency was attained through exercise and high energy breakfast (EHB), exercise and a low energy breakfast (ELB), a high energy breakfast without exercise (NEHB), or no exercise and low energy breakfast (NELB) (61). During ad libidum lunch approximately four hours after breakfast, the response to this energy deficiency on food consumption and mood was assessed. For those who consumed a low energy breakfast, cravings and dietary energy intake at lunch both increased while exercise did not show any affect on either cravings or dietary energy intake at lunch. These findings are a prime example of the uncoupling between EI and EEE. Taking into consideration this possible uncoupling between EI and EEE, total daily dietary energy and macronutrient intake may be negatively affected as a result of inadequate EI. Due to this uncoupling, energy balance may not be possible and low EA may occur.

Though it would be ideal for each individual sport to be provided with nutritional recommendations to optimize training and energy status, this may be difficult due to the possible differences that each may present. Energy availability, however, has been identified as an easy way of monitoring energy status (62). For competing athletes, effective monitoring of energy status is important as this may prevent the onset of low EA, inadequacies in nutrient consumption, and thus negative physiological consequences such as menstrual disturbances (19, 23), lower resting metabolic rate (RMR) (23), low bone mineral density (BMD) (9), and increased risk of stress fractures (48). Due to the necessity of estimating EI and EEE, as well as measuring LBM, determining EA may not be practical for many exercising women. For this reason, adherence to the ACSM recommendations for nutrition and athletic performance for carbohydrate intake may be an easier and more effective means of monitoring energy status. In fact, it was shown that Division I female soccer players who meet the recommendations for carbohydrate intake were more likely to have a higher EA. In order to insure optimal dietary intake, and potentially energy status, policy changes by the NCAA permitting the provision of adequate foods and supplements to university athletes may be necessary.

Nutritional practices such as the energy density at particular meals was also assessed in order to determine dietary energy distribution. Interestingly, Reed et al. (11) observed that exercising women with amenorrhea consumed a diet lower in energy density when compared to ovulatory controls. In the current study, Division I female soccer players with low energy availability consumed lower energy dense meals at lunch and dinner during the pre and mid season, respectively. During the pre season, players were responsible for purchasing or preparing their own lunches, while immediately following a game, dinner was catered. In one study of male and female Division I athletes, it was observed that a greater consumption of foods that were "prepared away from home" was positively associated with surpassing the recommendations for fat (35). This can provide great insight that individuals that eat at home may consume less dietary fat, decreasing energy density, and possibility resulting in lower EI and EA. These findings suggest that Division I female soccer players that consume a lower energy dense foods at particular meals may be more apt to consume a total diet associated with lower energy density. Taking such a diet into consideration as well as the possibility that EEE may not be fully compensated through EI, these athletes may be at increased risk of developing low EA, and thus disturbances in menstrual and bone health (4, 61). Such findings are important in the field of sports and exercise nutrition because healthcare providers in the field may now have an easier way to monitor and prevent the development of such conditions (62).

This study was the first to examine nutritional changes across the competitive season as well as the distribution of calories from a variety of dietary sources in Division I female soccer players. The four categories of assessment were food, sports drinks, other drinks, and bars/beans/gels. Though there was no significant difference between the low or high EA groups with respect to the distribution of dietary energy intake, the majority of dietary intake came from the "food" category. Division I female soccer players with high EA consumed 79.3% of total calories from "food" and Division I female soccer players with low EA consumed 83.6% of total calories from "food." The next highest distribution of dietary energy intake of either group came from the "sport drink". Division I female soccer players with high EA consumed 8.8% of total calories from this category while Division I female soccer players with the low EA consumed only 5.9% of total calories. Due to the great proportion of energy distribution from the "food" category, it will be important for elite athletes such as Division I female soccer players as well as their coaches, trainers, and staff to understand the basic principles of nutrition related to sports and physical activity. At certain times before or during the competitive season, athletes may be required to take part in multiple training sessions per day, i.e. "two-a-days" in football or soccer which occurred during the pre season of this study.

Due to a possible increase in energy requirements as a result of increased energy expenditure, greater energy and macronutrient intake may be required to maintain energy balance. Further understanding of concepts such as benefits of increased energy intake or the pros and cons of supplementation may be beneficial in optimizing EA through adequate dietary intake from a variety of food sources.

Limitations of this study include dietary collection by means of 3-day diet logs which have previously shown inaccuracies through underreporting (63). In order to improve the accuracy of the 3-day diet logs, all participants were trained on proper recording procedures, provided with educational packets which contained diagrams illustrating container sizes, cuts of meat, and various circles and squares which are used when estimating portion sizes for foods. Also included in the packet was a sample page of an accurately completed diet record provided as a reference. Another limitation of the current study is the sample size. This small sample size may have contributed to difficulties in detecting significant differences between groups. Sample size at the pre, mid, and post season periods fluctuated due to the non-compliance of a number of subjects at certain time points throughout the season.

As division I female soccer players are typically underreported, this group of elite athletes will be important to examine in future trials because they may be at an increased risk of developing the Female Athlete Triad. These athletes may be at greater risk due to certain dietary strategies associated with low EA. Future studies should concentrate on educating participants on proper dietary and exercise recording procedures in order to insure accurate dietary assessment. Most importantly, future analyses should attain a larger sample size for all points of the competitive season. Sample size in the current study fluctuated throughout the pre, mid, and post season periods and may have contributed to the lack of significant differences between seasonal time points. An adequate number of participants may provide sufficient date to observe significant changes throughout the season, and thus provide greater insight into specific dietary practices that are associated with low EA.

This study was the first to examine the dietary energy intake of Division I female soccer players at several time points across the competitive season and nutritional practices that may be associated with low EA. We determined that Division I female soccer players with low EA have a greater likelihood of not meeting ACSM recommendations for nutrition and athletic performance for carbohydrate intake (2). It was also determined that Division I female soccer players with high EA consumed 79.3% of total calories from “food” and Division I female soccer players with low EA consumed 83.6% of total calories from “food.” Finally, players with low EA consumed a lower energy dense diet at particular meals such at lunch when soccer players were responsible for preparing or purchasing their own foods or at dinner when it followed a game. Insight into the dietary habits and nutritional strategies of elite female soccer players will assist in the progression of the field of nutrition and exercise science pertinent to these athletes. Monitoring and evaluation of common nutritional practices associated with low EA will be important in order to prevent low EA conditions which have been associated with unfavorable reproductive, bone, and metabolic health.

Resources

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Academic Vita

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EDUCATION

The Pennsylvania State University- Nutritional Sciences — University Park, Pa

Honors in Kinesiology

WORKS IN PROGRESS

Undergraduate Honors Thesis

- "*Nutritional practices associated with low energy availability in Division I female soccer players*"
-Expected Date of Completion: April 2012

Energy Density Paper

-"*Nutritional practices associated with low energy availability in Division I female soccer players*"
-Expected Date of Completion: May 2012

PERTINENT EXPERIENCE

Women's Health and Exercise Lab- January 2011 to present — University Park, Pa

-*Directors: Drs. Nancy Williams and Mary Jane DeSouza*

- *Daily duties include aliquoting blood and urine, literature review, compiling data, and writing an honors thesis and research paper on the topic of nutritional strategies in a population of Division I female soccer players. Experience with underwater weighing and* VO_{2Max} *technologies.*

Student Sports Nutritionist- May, 2011 to August, 20122 — University Park, Pa

- *Daily duties include counseling athletes on nutritional habits, creating educational material, and performing body composition tests using the BodPod.*

Sodexo, Inc- May 2010 to August 2010 — Harrisburg, Pennsylvania

-*Performed meal rounds, patient surveys, food safety tests, dietitian shadowing, and independent projects for the dietitians and food service manager at the Harrisburg Hospital.*

EDUCATIONAL ACHIEVEMENTS

Schreyer Honors College

-*Research based honors program.*

Kappa Omicron Nu

-*College of Health and Human Development Honors Program*

Dean's List (GPA > 3.50)

-*Fall 08, Spring 09, Fall 09, Spring 10, Fall 10, Spring 11, Fall 11*

4.0 GPA

-*Spring 11, Fall 11*

PROFESSIONAL PRESENTATIONS

Honors Thesis Research Proposal Presentation- May, 2011 University Park, Pa

-*Poster presentation on the topic of "The effects of hydration status on athletic performance in Division I female soccer players"*

Honors Thesis Poster Presentation- Future date: May 4, 2012 University Park, Pa

-"*Nutritional practices associated with low energy availability in Division I female soccer players*"

CLUBS AND ORGANIZATIONS

Academy of Nutrition and Dietetics- September 2011 to present

-*Student member*

Student Nutrition Association University Park, Pa

-*General member*

Lion Ambassadors- January 2009 to December 2010 Altoona, Pa

-*Toured potential students around campus and took part in community service opportunities*

CERTIFICATIONS AND LABORATORY TRAINING

Servsafe Certification: Certification number: 7426042

-Food safety certification

Penn State Laboratory Training

-Human Subject Training for Biomedical Research

-NIH Protecting Human Research Participants Training

-Bloodborne Pathogen Training

-Chemical and Hazardous Waste Handling Training

-Radiation Safety Training for Ancillary Personnel