ASSESSMENT OF THE RANGE OF ENERGY AVAILABILITIES AND THE PREVALENCE OF LOW ENERGY AVAILABILITY AMONG FEMALE ENDURANCE ATHLETES

by

Kimberly A. Henderson

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STATEMENT OF THESIS APPROVAL

The thesis of **Kimberly A. Henderson**
has been approved by the following supervisory committee members:

Katherine Beals	, Chair	6/17/2011 Date Approved
Kristine Jordan	, Member	6/17/2011 Date Approved
Stacie Wing-Gaia	, Member	6/17/2011 Date Approved

and by **Eldon Wayne Askew**, Chair of the Department
of **Nutrition**

and by Charles A. Wight, Dean of The Graduate School.

ABSTRACT

Research indicates that energy availability below 30 kcal•kg FFM^{-1}•day^{-1} suppresses reproductive hormones and markers of bone formation while energy balance is hypothesized to occur at an energy availability of 45 kcal•kg FFM^{-1}•day^{-1}. Nonetheless, available evidence suggests that few female athletes achieve energy availabilities of 45 kcal•kg FFM^{-1}•day^{-1} and little is known about the effects of energy availabilities between 30 and 45 kcal•kg FFM^{-1}•day^{-1}**.** This study examined the range of energy availabilities and the prevalence of low energy availability (currently defined as ≤ 30 kcal•kg^{-1} FFM•day^{-1}) among female endurance athletes. Subjects were 40 female endurance athletes from the Salt Lake City area. Dietary patterns and eating behaviors were assessed by a health, weight, dieting, and eating patterns questionnaire. Energy availability was assessed via 3-day diet and activity records designed to capture three distinct training days (heavy, moderate and easy). Exercise energy expenditure was calculated using the Ainsworth Compendium For Physical Activity. Energy availability for the sample ranged from 7.6 to 54.1 kcal•kg^{-1} FFM•day^{-1} with a mean of 27.8 kcal•kg^{-1} FFM•day^{-1}. The majority of subjects (62.5%) (n=26) of subjects had an energy availability ≤ 30 kcal•kg^{-1} FFM•day^{-1}, while only 5.0% (n=2) of subjects had an energy availability ≥ 45 kcal•kg^{-1} FFM•day^{-1}. Those athletes with energy availabilities ≤ 30 kcal•kg^{-1} FFM•day^{-1} did not demonstrate a greater incidence of stress fractures or menstrual dysfunction. These preliminary data indicate that endurance athletes routinely

demonstrate energy availabilities below the “optimal range”, and that low energy availability is not predictive of menstrual function or bone health.

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INTRODUCTION

Research examining females taking part in exercise and competitive sports on a regular basis has increased substantially over the last 20 years and, as a result, the impact of exercise on females' health has received considerable attention. The cumulative results of this research indicate that regular physical activity helps manage stress, supports weight management, decreases the risk of breast cancer, and reduces the risk of heart disease among women (1). Nonetheless, despite the well-documented benefits of exercise, for a small segment of the athletic female population, participation in athletics may predispose the athlete to engage in disordered eating behaviors, leading to menstrual dysfunction and compromised bone health.

In 1992, the Task Force on Women's Issues of the American College of Sports Medicine (ACSM) coined the term female athlete triad to highlight the fact that the conditions seen in some female athletes--disordered eating, menstrual dysfunction, and osteoporosis--often occur together and appeared to be interrelated (1). Research documenting what was known at the time regarding the prevalence, causes, prevention, treatment, and consequences of the Triad was published in the 1997 ACSM Position Stand. Ten years later, as a result of additional research and knowledge regarding the Triad, ACSM published a revised Position Stand on the Triad (2, 3). The 2007 Position Stand renamed the categories, took a broader view of them, and described each component as more of a spectrum than the original more rigid definitions (3). Most significantly, the revised Position Stand identified low energy availability as the cornerstone of the metabolic and health consequences associated with the triad.

Energy availability is defined as dietary energy intake minus exercise energy expenditure normalized for fat-free mass (3). Thus, energy availability is the amount of energy available for the metabolic processes of the body after energy is used for exercise (4). A reduction in energy availability below 30 $kcal \bullet kg\ FFM^{-1} \bullet day^{-1}$ has been shown to suppress reproductive function (5) and bone formation (6). In healthy females, it is hypothesized that energy balance occurs at an energy availability of approximately 45 $kcal \bullet kg\ FFM^{-1} \bullet day^{-1}$ (7). Nonetheless, there is currently no data supporting this notion, nor is there data delineating the effects of energy availabilities between 31 $kcal \bullet kg\ FFM^{-1} \bullet day^{-1}$ and 44 $kcal \bullet kg\ FFM^{-1} \bullet day^{-1}$ and thus their impact on the health of the athlete.

Low energy availability results from insufficient energy intake to meet the added energy demands of exercise. Long periods with low energy availability, with or without disordered eating, can impair health and physical performance (3). Medical complications can occur in the cardiovascular, reproductive, endocrine, gastrointestinal, renal, and central nervous systems (3). In addition, low energy availability can impair cognitive function and decrease the body's ability to build bone, maintain muscle mass, repair damaged tissue, and recover from injury (7).

Low energy availability may result from the athlete unintentionally failing to meet energy requirements due to time constraints, food availability issues, or lack of appropriate nutrition knowledge (8). Athletes may also put themselves in a state of low energy availability in an attempt to optimize weight or body composition for competitive success using normal eating behaviors (8).

Athletes participating in sports with an aesthetic component or sports that emphasize leanness or low body weight are believed to be at a higher risk for developing disordered eating and consequently, low energy availability (9). However, several studies suggest a similar risk for eating disorders for female gymnasts (10) and endurance runners (11) compared with nonathletic controls.

The prevalence of inadvertent low energy availability is currently unknown, largely due to a lack of studies specifically designed to examine prevalence and discrepancies in the definition of low. In a 2007 review, Manore et al. estimated the average energy availabilities from seven published studies involving energy intake and expenditure among female athletes. These authors found that the mean energy availability for all athletes was 29.7 kcal•kg FFM^{-1}•day^{-1} and five studies found mean energy availabilities in the "low" category (defined as < 30 kcal•kg FFM^{-1}•day^{-1}). Interestingly the range of energy availabilities among the eumenorrhoeic athletes was quite large, from 19 to greater than 45 kcal•kg FFM^{-1}•day^{-1} (7). In 2009, Hoch et al. examined the prevalence the components of the triad, including energy availability in high school athletes and sedentary controls (12). Thirty-six percent of the athletes and controls were categorized as having "low" energy availability; however, it should be noted that low energy availability was defined as less than or equal to 45 kcal•kg FFM^{-1}•day^{-1} (12).

The specific objectives of this study were to examine the range of energy availability among female athletes in the greater Salt Lake City area and determine the prevalence of low energy availability (defined as $\leq$ 30 kcal•kg^{-1} FFM•d^{-1}). We hypothesized that a wide range of energy availabilities exist among athletes, and that few would meet the currently considered "optimal level" of 45 kcal•kg FFM^{-1}•day^{-1}

METHODS

Research Design

This descriptive study examined the range of energy availabilities among female endurance athletes and sought to determine the prevalence of low energy availability as defined by existing energy availability categories. All subjects represented a purposive sample recruited with strict selection criteria.

Subject Selection Criteria

Study eligibility criteria included the following: premenopausal female athletes between the ages of 18 and 45 years who train a minimum of 8 hours per week. Exclusion criteria included pregnancy and menopause. Fifty women were contacted during April and May 2011. Forty women met the eligibility criteria and agreed to participate in the study. Consent and assent forms were obtained for all participating subjects. The health, weight, eating and dietary patterns questionnaire, 3-day food and activity log were collected at the convenience of the subject. Protocol approval from the Institutional Review Board of the University of Utah was obtained prior to the start of the study.

Data Collection

Assessment of Health, Weight, Dietary Patterns and Eating Behaviors

Dietary patterns and eating behaviors were assessed by a health, weight, dieting, and eating patterns questionnaire that was developed and used by the principal investigator in previous research examining the prevalence of the Triad in female collegiate athletes (8, 13). Content validity was established through a review of the questionnaire by a panel of experts in the area of eating practices among athletes. The questionnaire ascertained demographic information (e.g., age, height, weight, ethnicity), primary sport, previous diagnoses of stress fractures, history of amenorrhea, musculoskeletal injury history, and eating behaviors.

Anthropometric Measures

Height in inches and weight in pounds were measured without shoes using a calibrated stadiometer and beam scale, respectively, and values derived were subsequently converted into centimeters and kilograms, respectively. Body composition (fat mass and fat free mass) was measured with a Tanita Segmental Body Composition Analyzer (model BC-418, Arlington Heights, IL, USA). Athletes were instructed to not eat or exercise the morning of the test. They were told they could drink water (but refrain from coffee and other beverages) the morning of the test. Proper hydration status was ensured by confirming that the subject's total body water was at least 60% of their total body weight. Resting metabolic rate was measured by indirect calorimetry (Korr ReeVue, Salt Lake City, UT, USA). Measurements were made in the morning between 5:30 and 8:00 AM to accurately measure subjects as close to their resting state as possible. Subjects were also required to rest quietly for 10 minutes immediately prior to measurement.

Assessment of Energy Availability

Energy availability, defined as the amount of dietary energy remaining for other bodily functions after energy expended in exercise training, was measured via 3-day food and exercise logs and was calculated using the following equation:

$$\textbf{Energy Availability} = \frac{\textbf{Mean Energy Intake} - \textbf{Mean Exercise Energy Expenditure}}{\textbf{Fat Free Mass}}$$

Energy intake was determined via a 3day food record in which subjects measured and recorded all the food and beverages they consumed for 3 training days (heavy, moderate, and easy). For a sample dietary intake form, see Appendix A. Subjects were trained in the level of detail required to adequately describe the foods and amounts consumed, including the name of the food (brand name, if applicable), preparation methods, recipes for food mixtures, and portion sizes. The 3-day dietary records were analyzed using ESHA Food Processor (versions 9.1.0, ESHA Research, Salem, Oregon).

Energy expended in exercise training on the same days that food intake was recorded was assessed via exercise logs. Subjects recorded the type, duration, and intensity of exercise performed on each of the 3 days. Exercise Energy expenditure was calculated from the Ainsworth Compendium for Physical Activities (14, 15).

Statistical Methods, Data Analysis and Interpretation

Predictive Analytics SoftWare Statistics (version 18 SPSS Inc., Chicago, IL, USA) was used to conduct data analyses. Continuous demographic variables (age, height, weight, fat free mass, etc.) are presented as means and standard deviations unless otherwise noted. Energy availability was examined as both a continuous variable (to determine the mean and range of energy availabilities of the sample) and categorically using the following established categories (3):

(1) Low energy availability: ≤ 30 kcal•kg FFM^{-1}•day^{-1}

(2) Suboptimal energy availability: 31- 44 kcal•kg FFM^{-1}•day^{-1}

(3) Adequate energy availability: ≥ 45 kcal•kg FFM^{-1}•day^{-1}

Where comparisons between energy availability groups were made, one-way analysis of variance (ANOVA) was used. When a significant F-ratio was found, Tukey HSD post hoc tests were conducted to determine which groups differed. Unless otherwise stated, *p* values are reported for the initial ANOVA. χ^2 analyses were used to determine differences between energy availability groups regarding menstrual irregularity, history of amenorrhea and stress fracture occurrence. The overall experimental-wise alpha was set at $p < .05$.

RESULTS

Description of the Sample

Forty female athletes, representing six sports, completed the study. Table 1 depicts the primary sports represented by the sample. Running was the most common sport that subjects participate in, followed by triathlons. Many of the athletes had a long history of participation in their sport, with 42.5% (n=17) indicating they had been participating in their primary sport for greater than 10 years. A majority of the subjects (85%) (n=34) were Caucasian. Subject characteristics for the sample as a whole as well as split by energy availability categories are presented in Table 2.

Energy Availability

Energy availability, resting metabolic rate, energy intake, and exercise energy expenditure (averaged from the 3-day diet and activity records) as a whole as well as split by energy availability categories are presented in Table 3. The average energy availability of the entire group was 27.8 kcal•kg FFM^{-1}•day^{-1}. There were no significant differences in resting metabolic rate and exercise energy expenditure between the groups. However, the energy intake of the energy availability $\leq$ 30 kcal•kg FFM^{-1}•day^{-1}group was significantly lower than both the energy availability 31-44 kcal•kg FFM^{-1}•$day^{-1}$and the energy availability $\geq$ 45 kcal•kg FFM^{-1}•day^{-1} groups. Thus, the differences in energy availability were explained almost entirely by differing energy intakes (and not exercise energy expenditures).

Table 1. Primary Sports Represented by the Whole Sample

Primary Sport	% of Total (n=40)	
Running	47.5	(n=17)
Triathlons	20.0	(n=8)
Nordic Skiing	12.5	(n=5)
Cycling	10.0	(n=4)
Swimming	7.5	(n=3)
Tennis	2.5	(n=1)

Table 2

Descriptive Information for All Subjects and with Subjects Divided Into Energy Availability Categories

Variable	Total Sample[a] (n = 40)	EA[*] ≤ 30[a] (n = 26)	EA 31 – 44[a] (n = 12)	EA ≥ 45[a] (n = 2)	Significance
Age (y)	27 ± 5	28 ± 6	25 ± 3	21 ± 0	P = 0.04[b]
Height (cm)	168.9 ± 5.9	166.8 ± 6.1	169.3 ± 6.2	168.9 ± 1.8	P = 1.00
Weight (kg)	61.6 ± 12.9	64.6 ± 9.8	55.7 ± 17.6	58.0 ± 1.6	P = 0.13
BMI (kg/m^2)	22.0 ± 2.7	22.5 ± 3.0	21.2 ± 1.8	20.3 ± 0.1	P = 0.28
Body Fat (%)	21.4 ± 5.7	21.9 ± 6.5	20.7 ± 4.2	19.6 ± 0.7	P = 0.76
FFM[**] (kg)	49.3 ± 4.2	49.9 ± 4.8	48.5 ± 2.7	46.6 ± 1.6	P = 0.42

Note. [*]EA = energy availability
[**]FFM = fat free mass
[a]Values are means ± standard deviation
[b]Significant difference between EA ≤ 30 and EA ≥ 45

Table 3

Energy Availability, Resting Metabolic Rate, Energy Intake and Exercise Energy Expenditure Values for All Subjects and Subjects Split by Energy Availability Category

Variable	Total Sample[a] (n = 40)	EA[*] ≤ 30[a] (n = 26)	EA 31 – 44[a] (n = 12)	EA ≥ 45[a] (n = 2)	Significance
EA[1] (kcal•kg FFM^{-1}•day^{-1})	27.8 ± 9.9	22.3 ± 6.6	36.1 ± 3.3	49.8 ± 6.2	P = 0.00[b,c,d]
RMR[2] (kcal/24 hrs)	1621.8 ± 180.6	1640.5 ± 193.0	1582.3 ± 164.2	1615.5 ± 126.6	P = 0.66
EI[3] (kcal)[b]	1268.0 ± 541.3	1932.3 ± 466.3	2509.4 ± 425.2	2848.5 ± 495.7	P = 0.00[b,c]
EEE[4] (kcal)*	805.2 ± 436.5	856.6 ± 455.6	738.8 ± 422.5	536.0 ± 116.2	P = 0.51

Note. [*]Represents average over the 3 day recording period
[1]EA = energy availability
[2]RMR = resting metabolic rate
[3]EI = mean energy intake
[4]EEE = mean exercise energy expenditure
[a]Values are means ± standard deviation.
[b]Significant difference between EA ≤30 and EA 31-44
[c]Significant difference between EA ≤30 and EA ≥ 45
[d]Significant difference between EA 31-44 and EA ≥ 45

Figure 1 shows the percentage of subjects in each previously defined category of energy availability. Utilizing the categories previously identified in the literature (5), 26 (62.5%) subjects had "low" energy availability (e.g., an energy availability less than or equal to 30 kcal•kg FFM^{-1}•day^{-1}. Twelve (32.5%) subjects had "suboptimal" energy availability (e.g., an energy availability between 31 and 44 kcal•kg FFM^{-1}•day^{-1}). Only 2 (5.0%) subjects had "adequate" energy availability (e.g., an energy availability greater than or equal to 45 kcal•kg FFM^{-1}•day^{-1}).

Pathogenic Weight Control Behaviors

Given the number of athletes with energy availabilities of less than 30 kcal•kg FFM^{-1}•day^{-1}, it is not surprising that many of the athletes reported purposely trying to control their weight. Responses from the health, weight, and diet history questionnaire indicated that 47.5% (n=19) of the athletes consciously restricted energy intake to control their weight and 75% (n=30) of the athletes indicated purposely restricting the types of foods they ate for weight control. Eighteen (45%) of athletes reported an "out of control eating" episode. Only 3 subjects (7.5%) self-reported a clinical diagnoses of an eating disorder. Nonetheless, 70% (n=28) of the athletes self-reported the use of pathogenic weight control behaviors. Figure 2 depicts the type and frequency of various pathogenic weight control behaviors practiced by athletes. A majority of the subjects (57.5%)(n=23) reported using additional exercise beyond regular /necessary training for their sport to control their weight. Additionally, a large percentage (40%) (n=16) indicated that they had utilized a high protein/low carbohydrate diet.

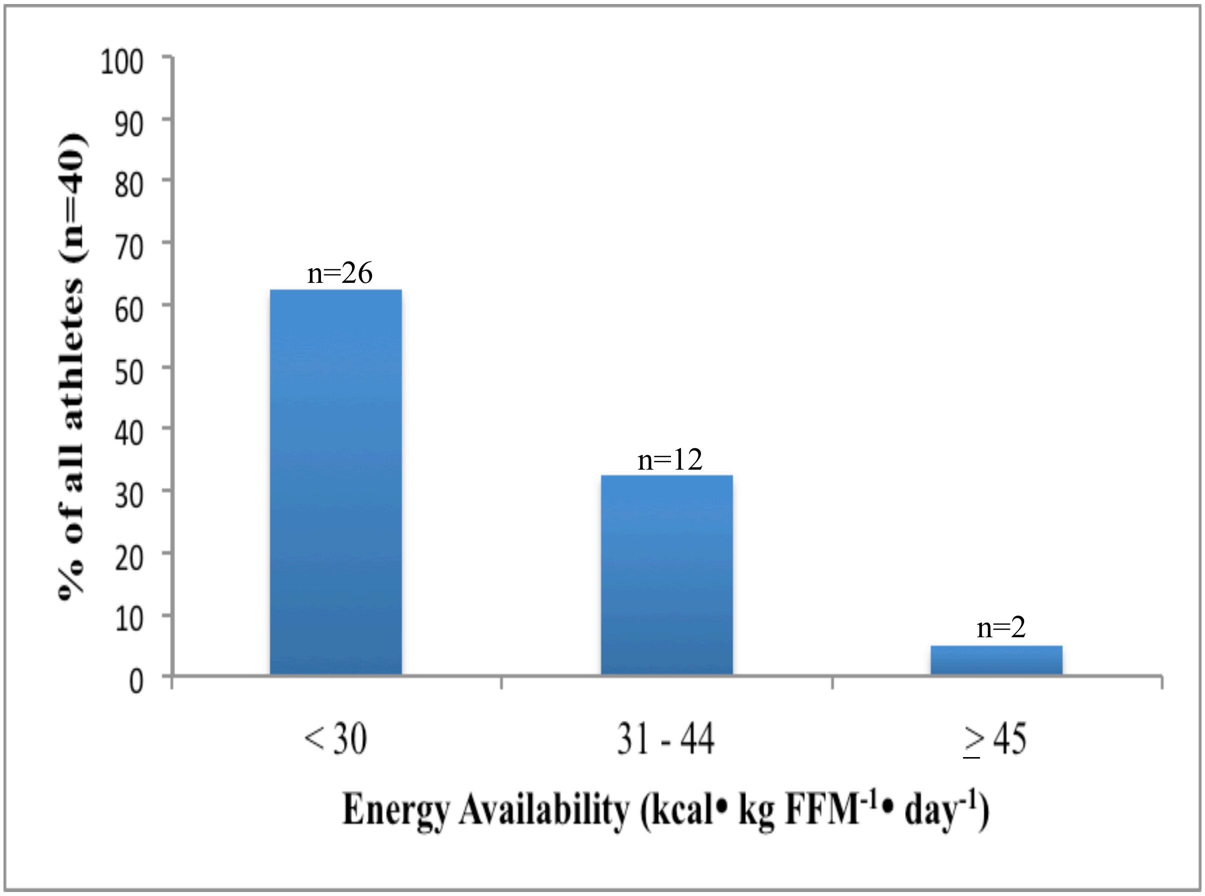

Figure 1. Percentage and Number of Subjects in Each Energy Availability Category

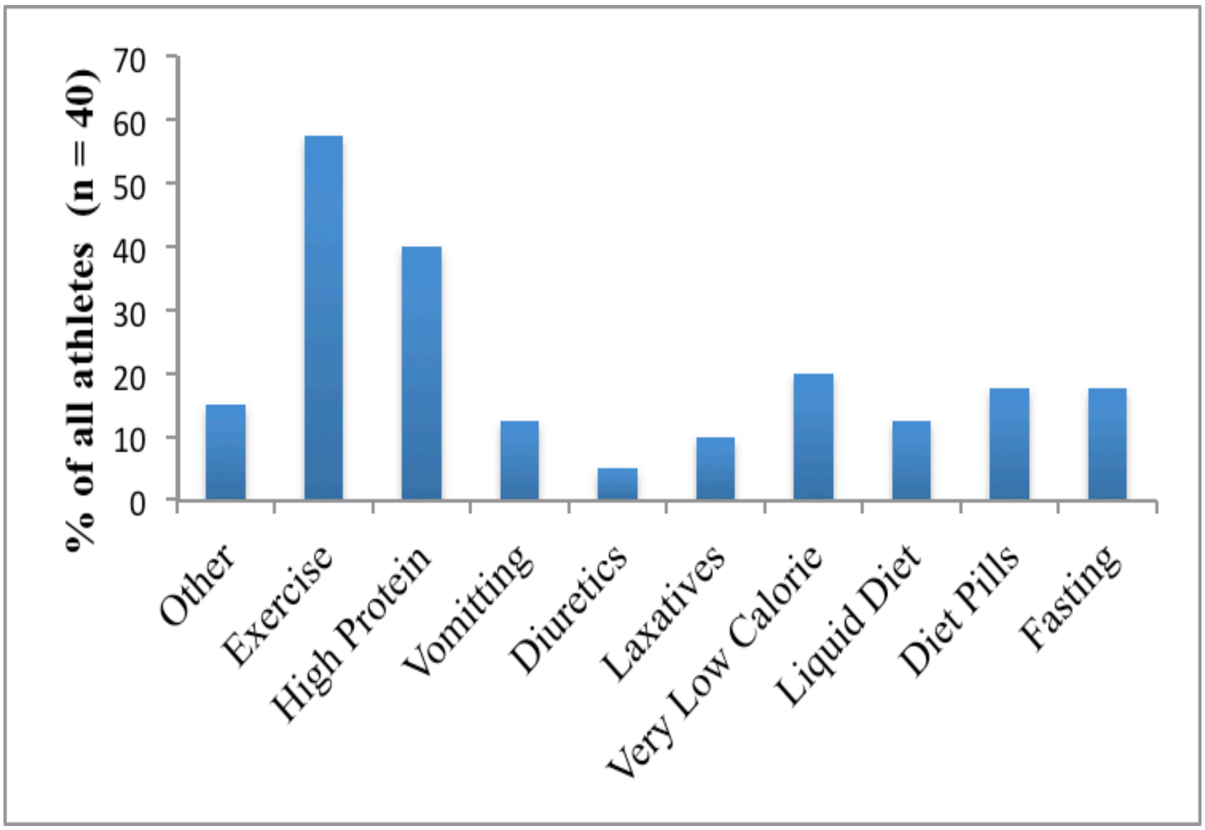

Figure 2. Percentage of All Subjects Reporting Practicing Pathogenic Weight Control Methods

Low Energy Availability, Stress Fracture History, and Menstrual Dysfunction

It has been hypothesized that disruptions in menstrual cycle and bone metabolism occur at an energy availability of $\leq$ 30 kcal•kg FFM^{-1}•day^{-1} (5). Thus, we examined whether the incidence of stress fractures and menstrual dysfunction were greater amongst those athletes with energy availabilities $\leq$ 30 kcal•kg FFM^{-1}•day^{-1}. As shown in Table 4, those athletes with energy availabilities $\leq$ 30 kcal•kg FFM^{-1}•day^{-1} did not demonstrate a greater incidence of stress fractures or menstrual dysfunction. Nine subjects reported at least one stress fracture diagnosis. In total, 20 stress fractures were recorded for those nine subjects. There was no significant difference in the number of stress fractures between athletes with energy availabilities $\leq$ 30 kcal•kg FFM^{-1}•day^{-1}. A majority of subjects (57.5%)(n=23) had a history of amenorrhea with 50% (n=20) currently experiencing menstrual irregularity.

Table 4. The Relationship Between Those Athletes with Low Energy Availability and Stress Fracture Incidence, History of Amenorrhea, and Menstrual Irregularity

Variable	% of Total Sample[a] (n = 40)	% with EA* ≤ 30	% with EA > 30	Significance
≥ 1 Stress Fracture (n = 9)	22.5 (n=9)	55.6 (n=5)	44.4 (n=4)	P = 0.69
No Stress Fracture (n = 31)	77.5 (n=31)	67.7 (n=21)	32.2 (n=10)	P = 0.69
Amenorrhea (n = 23)	57.5 (n=23)	60.8 (n=14)	39.2 (n=9)	P = 0.74
No History of Amenorrhea (n = 17)	42.5 (n=17)	70.5 (n=12)	29.5 (n = 5)	P = 0.74
Irregular (n = 20)	50.0 (n=20)	55.0 (n=11)	45.0 (n=9)	P = 0.32
Regular (n = 20)	50.0 (n=20)	75.0 (n=15)	25.0 (n=5)	P = 0.32

Note *EA = energy availability

DISCUSSION

The primary aims of this study were to examine the range of energy availabilities among a group of female endurance athletes and determine the prevalence of low energy availability (defined as < 30 kcal•kg^{-1} FFM•day^{1}). Though many researchers have examined the energy intake of female athletes, few have systematically and purposely measured energy availability (7). Moreover, the few studies examining the prevalence of the energy availability as part of the Female Athlete Triad, have used different criteria to define “low” energy availability. In their review paper, Manore et al. (7) set the threshold for identifying low energy availability at $\leq$ 30 kcal•kg^{-1} FFM•d^{-1}, while Hoch et al (12) classified low energy availability as $\leq$ 45 kcal•kg^{-1} FFM•d^{-1}. Thus, universally accepted categories to delineate “low” and “adequate” energy availability remain undetermined.

We found the mean energy availability of the total sample (n=40) was 27.8 kcal•kg^{-1} FFM•day^{1}. In fact, the majority of the athletes in this study (62.5%)(n=25) had energy availabilities $\leq$ 30 kcal•kg^{-1} FFM•day^{1} (the value currently considered to be “low”) while only 5.0% (n=2) of subjects had an energy availability > 45 kcal•kg^{-1} FFM•day^{1} (the value currently considered to be “optimal”). The mean energy availability of subjects in this study is consistent with the findings of Manore et al. (7) who found the mean energy availability of female endurance athletes, calculated from studies conducted between 1991 and 2006, was 29.7 kcal•kg FFM^{-1}•day^{-1}. It is notable that both Manore’s value and our value of mean energy availability are below the hypothesized cutoff for “low” energy availability ($\leq$30 kcal•kg FFM^{-1}•day^{-}). The prevalence of low energy availability among the athletes in this study differs from the findings of both Hoch (12) and Garneau-Fournier (16). In 2009, Hoch (12) examined the prevalence of each of the components of the triad among 80 high school athletes, and found that 36% (n=28) of the athletes demonstrated low energy availability. It should be noted Hoch studied high school athletes, while we examined female endurance athletes between the ages of 18-45 yr in this study. In addition, Hoch defined low energy availability as $\leq$ 45 kcal•kg FFM^{-1}•day^{-1}, perhaps boosting the already small percentage of athletes with low energy availability (12). In a more recent study, Garneau-Fournier et al. (16) found that the prevalence of low energy availability (defined as <30 kcal•kg FFM^{-1}•day^{-1}) was 37% (n=7), also quite a bit lower than the value we found. While a majority (64%) (n=52) of the athletes assessed by Hoch met the current hypothesized optimal energy availability level (> 45 kcal•kg^{-1} FFM•d^{-1}), only 5.0% (n=2) of our athletes had an energy availability > 45 kcal•kg^{-1} FFM•d^{-1}. In light of these differences, and given the fact that there was no association between energy availability levels and either menstrual dysfunction and stress fracture history in our study, further research is needed to determine if a redefinition of the energy availability categories is warranted.

Indeed, ours is not the only research that suggests that the current categories of energy availability may be incapable of differentiating menstrual status in premenopausal female athletes. It should be noted that in the studies by Loucks (4, 5) indirect markers of menstrual function (i.e., luteinizing hormone pulse frequency) and bone health (markers of bone formation) were utilized. While energy availability below 30 kcal•kg^{-1} FFM•d^{-1} (specifically, 10 kcal•kg^{-1} FFM•d^{-1} in Louck's study) may have short-term effects on menstrual cycle hormones, this does not seem to translate into the long-term outcomes of amenorrhea or stress fracture incidence. De Souza et al. (17) published an abstract that shows the cutoff for low energy availability (e.g., < 30 kcal•kg FFM^{-1}•day^{-1}) provides a highly specific, but not a particularly sensitive measure, to differentiate menstrual status in exercising premenopausal women. The fact that energy availability is an acute (e.g., disruption of luteinizing hormone pulse frequency), not chronic (amenorrhea), indicator of energy deficiency in amenhorreic women may be the reason for the reduced sensitivity observed by DeSouza et al. It is also possible that there are multiple and still unidentified contributors to menstrual dysfunction in athletic women.

In this study, subjects with energy availabilities ≤ 30 kcal•kg^{-1} FFM•day^{1} did not demonstrate a greater incidence of menstrual dysfunction or stress fractures than athletes with an energy availability > 30 kcal•kg^{-1} FFM•day^{1}. These results coincide with Manore's findings that demonstrated eumenorrheic athletes had energy availabilities ranging from 19 to greater than 45 kcal•kg^{-1} FFM•day^{1} (7). Our results suggest that an energy availability of ≤ 30 kcal•kg^{-1} FFM•day^{1} may not be an appropriate marker of menstrual function and bone health in female athletes. The association between energy availability, menstrual function, and bone health appears to be highly individualized with some athletes reporting menstrual dysfunction at an energy availability > 30 kcal•kg^{-1} FFM•day^{1} while others are able to maintain menstrual function and bone health even at low energy availabilities. Further research into the cause of these individual differences is warranted in order to better understand why some athletes can seemingly function at a lower level of energy availability whereas others have menstrual dysfunction and low bone mineral density.

Until 2007, when the ACSM redefined the categories of the triad and replaced "disordered eating" with "energy availability" studies on the prevalence of the components of the female athlete triad examined "disordered eating" behaviors. In this study only three athletes (7.5%) reported a clinical diagnosis of an eating disorder; however, 47.5% (n=19) of athletes reported restricting their energy intake to control their weight and 75% (n=30) of the athletes disclosed purposely restricting the types of food they eat to control their weight. Pathogenic weight control behaviors (e.g., additional exercise, high protein or very low calorie diets, self-induced vomiting, use of diet pills, laxatives. or diuretics, or liquid diet products) place athletes at an increased risk for disordered eating and consequently, "low" energy availability (18). Seventy percent (n=28) of the athletes in this study self-reported the use of pathogenic weight control behaviors. Additional exercise beyond regular training was the most common method of weight control, utilized by 57.5% (n=23) of subjects, followed by consumption of a high protein/low carbohydrate diet (40%)(n=16). Such behaviors have serious implications for endurance athletes. Loucks et al. found that low energy availability, caused by dietary energy restriction, greatly reduced carbohydrate intake (4). Consequently, skeletal muscle derived much less energy from carbohydrate oxidation in the state of deprived energy availability compared to adequate energy availability (4). Performance in a high-intensity endurance activity, fueled primarily by glucose metabolism, may be compromised by inadvertent low energy availability or low carbohydrate diets.

There are several potential limitations to examining energy availability. Currently, there is no standardized clinical approach to measuring energy availability. In addition, many athletes with the triad often try to hide their symptoms from their families, friends, coaches, and teammates. Gathering accurate self-reported caloric intake and energy expenditure data is especially difficult in athletes. Thus, accurate assessments of energy availability pose a certain challenge. We chose to use a 3-day dietary record, the current gold standard for assessing energy intake (19), because recording periods of more than 4 consecutive days are usually less accurate, as reported energy intake decreases because of respondent fatigue (20). Exercise energy expenditure was measured from established guidelines (14, 15). Both measurements have limitations related to accuracy and honesty of the subjects. Several studies indicate that reported energy and protein intakes on diet records for selected small samples of adults are underestimated in the range of 4% to 37% when compared to energy expenditure as measured by doubly-labeled water or protein intake as measured by urinary nitrogen (21). Underreporting on food records is probably a result of the combined effects of incomplete recording and the impact of the recording process on dietary choices leading to undereating. Portable metabolic devices, such as accelerometers, may provide more accurate measures of exercise energy expenditure than self-reported data, but are also more cumbersome and require calibration and strict adherence to protocol.

Another limitation of measuring energy availability in this study was the small sample size. Thus, our results may not be representative of the entire athletic population. In addition, a majority of our participants were self-selected. Those with experience of the triad or a particular interest in nutrition or health issues may have been more inclined to respond resulting in sample bias.

CONCLUSION

Current understanding of the female athlete triad places low energy availability as the key disorder underlying all of the components of the triad. Long periods of low energy availability, with or without disordered eating, can impair both health and physical performance. These data indicate that endurance athletes routinely demonstrate energy availabilities below the currently hypothesized "optimal range", and that low energy availability is not a sensitive measure of menstrual function or bone health. Rather, the association between energy availability, menstrual function, and bone health appears to be highly individualized and requires further research to understand why some athletes can maintain menstrual function and bone health at a lower level of energy availability whereas others have menstrual dysfunction and low bone mineral density.

APPENDIX

HEALTH HISTORY QUESTIONNAIRE

Athlete Health/Nutrition Survey

Please complete both sides of the survey. Responses will remain CONFIDENTIAL

Demographic Information

1. Birthdate (mo/day/yr) _____/______/______ 2. Age (yrs) ________

3. Ethnicity (check one): ☐African American ☐Asian ☐Caucasian ☐Hispanic ☐Native American ☐Other

4. Primary sport you participate in:______________________ 5. Years of participation: ______

6. Other sports you participate in regularly:______________ 7. Years of participation: ______

8. Are you now or could you possibly be pregnant? ☐YES ☐NO

Musculoskeletal History

1. Is there a history of osteoporosis in your family? ☐YES ☐NO

2. Have you ever been diagnosed with any of the following? (check all that apply)

☐ osteoporosis ☐ low bone density ☐ scoliosis ☐ any other bone disorder (describe)_______________

3. Have you ever been diagnosed by a doctor for a stress fracture from sport participation? ☐YES ☐NO

* If you answered ***YES***, how many stress fractures have you had? _____________

* If you answered YES, please indicate the *location* and *number* of stress fractures you have had:

Upper back	_________	Lower back	_________
Hip	_________	Pelvis	_________
Upper leg (femur)	_________	Lower leg	_________
Ankle	_________	Foot	_________
Toes	_________	Upper arm	_________
Lower arm	_________	Wrist	_________
Hand	_________	Fingers	__________

4. Have you ever suffered a soft-tissue injury (e.g., muscle, tendon or ligament) as a result of training or competition? ☐YES ☐NO

* If you answered ***YES***, how many soft-tissues injuries have you had? _______ (over lifetime)

* If you answered YES, please indicate the *location* and *number* of soft tissue injuries you have had:

Upper back	_________	Lower back	_________
Hip	_________	Pelvis	_________
Upper leg (femur)	_________	Lower leg	_________
Ankle	_________	Foot	_________
Toes	_________	Upper arm	_________
Lower arm	_________	Wrist	_________
Hand	_________	Fingers	_________

Menstrual History (women only)

1. Have you ever had a menstrual period? ☐ YES ☐ NO

2. How old were you when you had your first menstrual period? ___ (yr)

3. When was your last menstrual period? _____/____ (mo/yr)

4. How many menstrual periods have you had in the last 12 months? __

In the last 6 months? ___

5. Please describe the regularity of your cycle? (check one)

☐ I am very regular (within 3 days) ☐ I am somewhat irregular (4 – 10 day variation)

☐ I am very irregular (variation greater than 10 days)

6. Are there changes in your menstrual period during your competitive "season" ☐ YES ☐ NO

* If you answered ***YES*** **please indicate which of the following changes occur during the season: (check all that apply)**

☐ My period stops ☐ My period becomes irregular ☐ my period becomes lighter

☐ I skip periods ☐ my period comes more often ☐ other (describe)

7. Do your periods change with changes in your training regimen? ☐ YES ☐ NO

* If you answered ***YES***, please **indicate which of the following changes occur during the season: (check all that apply)**

☐ My period stops ☐ My period becomes irregular ☐ my period becomes lighter

☐ I skip periods ☐ my period comes more often ☐ other (describe)

8. Have you ***ever*** gone for 3 or more months without having a menstrual period? ☐ YES ☐ NO

* If you answered ***YES***, how many times have gone 3 or more months without having a period? _______

* If you answered ***YES***, how many months did you go without menstruating? ________

9. Have you gone for 3 or more months without menstruating during your competitive season?

☐ YES ☐ NO

* If you answered ***YES***, how many times have gone 3 or more months without having a period during your

competitive season? _______

* If you answered ***YES***, how many months did you go without menstruating during your competitive season?________

10. Do you currently take birth control pills or hormones? ☐ YES ☐ NO

* If you answered YES, why are you using them?

☐ birth control ☐regulate menstrual cycle ☐ both

* If you answered YES, how long have you been using birth control pills? (months) _____

Nutrition History

1. How many meals (i.e., breakfast, lunch, dinner) do you usually eat per day? (check one)

☐ 1 ☐ 2 ☐ 3 ☐4 ☐ 5 ☐ 6 ☐ more than 6

2. How many snacks (i.e., candy bar, sports bar, piece of fruit) do you usually eat per day? (check one)

☐ 1 ☐ 2 ☐ 3 ☐4 ☐ 5 ☐ 6 ☐ more than 6

3. Do you skip meals? ☐ YES, frequently ☐ YES, occasionally ☐ Rarely ☐ Never

4. Are you a vegetarian? ☐ YES ☐ NO

* If you answered ***YES***, please indicate which type:☐ vegan ☐ lacto/ovo ☐ lacto ☐other:__

5. Do you limit/restrict the ***amount*** of food you eat to control your weight? ☐ YES ☐ NO

6. Do you limit/restrict the ***types*** of food you eat to control your weight? ☐ YES ☐ NO

7. Do you ever feel out of control when eating or feel that you cannot stop eating? ☐ YES ☐ NO

8. Have you ever eaten a large amount of food rapidly (i.e., binged) ☐ YES ☐ NO
 * If you answered ***YES***, how often have you engaged in this behavior during the past year?

 ☐ < once/month ☐ ~ once/month ☐ 2-3 times/month ☐ ~ once/week ☐ > once/week ☐ daily

9. Have you ever purged after a binge? ☐ YES ☐ NO

 * If you answered ***YES,*** what type of purging did you engage in? (check all that apply)

 ☐ laxatives ☐ vomiting ☐ diuretics ☐ extra exercise ☐ sauna/sweatsuits

10. Do you think your diet is nutritionally adequate? ☐ YES ☐ NO

11. Have other people indicated that your eating habits are unusual or abnormal? ☐ YES ☐ NO

12. Do you think you might have an eating disorder? ☐ YES ☐ NO ☐ Maybe

13. Do you take vitamin or mineral supplements?

 ☐ YES, daily ☐ YES, but not every day ☐ NO

15. Please indicate the type(s) of supplement(s) you use (***check all that apply***)

 ☐ multivitamin/mineral ☐ iron ☐ calcium ☐ vitamin C ☐ vitamin E

 ☐ B-complex vitamins ☐ zinc ☐ herbals ☐ other (describe) _______

16. Do you use nutritional supplements or sports products?

☐ YES, daily ☐ YES, but not every day ☐ NO

17. Please indicate the type(s) of supplement(s) you use (***check all that apply***)

☐ protein powder/drink ☐ sports bar (Powerbar, Cliff bar, Luna bar) ☐ amino acids

☐ glutamine ☐ sports drinks (Gatorade, Powerade) ☐ "fat burners"(ephedrine)

☐ HMB ☐ hormones (androstendione, DHEA) ☐ chromium

☐ creatine ☐ other (please specify)

____

Weight History

1. Height ____/____ ft/in 2. Current Weight_____lbs 3. Time at current weight ______
4. What is your ideal weight? ________ lbs. 5. Ever been at your ideal weight? ☐Yes
6. How many times has your weight fluctuated by at least 5 lbs. in the last year? _______
7. How often are you trying to control your weight ***during*** the season?

☐ never ☐ rarely ☐ sometimes ☐ often ☐ always

8. How often are you trying to control your weight in the "*off season*" or when you reduce your training?

☐ never ☐ rarely ☐ sometimes ☐ often ☐ always

9. When your season is over and you stop or reduce your training do you (check one)

☐ Lose weight ☐ Gain weight ☐ Maintain weight

10. Which of the following are you currently trying to do about your weight? (check only one)

☐ Lose weight ☐ Gain weight ☐ Maintain weight ☐ I am doing nothing

11. I presently think of myself as being… (check only one)

☐ Very underweight (> 10 lbs.) ☐Slightly underweight (5 – 10 lbs.) ☐At an "ideal" weight

☐Slightly overweight (< 10 lbs.) ☐Moderately overweight (10 – 20 lbs.)

☐Very overweight (> 20 lbs.)

12. How satisfied are you with your current body weight?

☐ very satisfied ☐ somewhat satisfied ☐ neutral

☐ somewhat dissatisfied ☐ very dissatisfied

13. Have you ever been diagnosed with and Eating Disorder ☐ YES ☐ NO

* If yes please indicate the eating disorder diagnosis:

☐ anorexia nervosa ☐ bulimia nervosa ☐ eating disorder not otherwise specified

14. Please indicate which of the following methods you have used in your *lifetime* and *within the past year* to control your weight by *checking* the appropriate column:

3-DAY FOOD AND EXERCISE LOG

Instructions For Recording Food & Activity

FOOD INTAKE

1. You will need to record your intake for ***3 days***. Please record ***2 weekdays and 1 weekend day***. The days do not need to be consecutive but they should be "typical" (i.e., typical in terms of your normal eating habits/patterns)
2. Please indicate the date and circle the day of the week that you are recording at the top of the food record.
3. Record each food and beverage you consumed on a separate line.
4. When eating combination foods (e.g., sandwich, lasagna, stew, casserole, etc.) please separate the food/dish into its individual components as much as possible.
5. Record food and beverages in reasonably exact amounts: liquids in cups or fluid ounces; grains, cereals, pasta in cups (please indicate if the measure is dry or cooked); meats, fish, chicken in ounces, fruits & vegetables in cups.
6. Please specify if the food was consumed raw or cooked (and indicate the type of cooking method used). Also indicate if it was prepared from fresh, canned or frozen products.
7. Please indicate how the food was prepared; e.g., fried, baked, boiled, grilled, steamed, etc.
8. List brand names or sources wherever possible. If the food item is unusual (fat-free, international food, supplement) please enclose a label if possible.
9. For fruits, potatoes, chicken etc. please indicate if the skin was removed before consumption
10. Please be sure to indicate if dairy products, (i.e., milk, cheese, yogurt, etc.) was whole, low-fat, non-fat, etc.
11. Be sure to include all the little extras (e.g., sauces, gravies, candy, gum, etc.)
12. Provide any other information you think might be helpful. Remember the more accurate/specific you are with recording the more accurate we can be with the analysis.

ACTIVITY

1. Please record the exercise/training that you do on the days that you are recording your food intake. This would include any and all "training" as well as any significant lifestyle physical activity (e.g., riding your bike to school, walking to the grocery store, dancing at a club)
2. You should include:
    - the type of exercise (e.g., running, cycling, swimming, weight training)
    - the length of time you exercised in minutes (e.g., 30, 45, 55, 60 etc minutes)
    - the distance you covered if appropriate (e.g., 3 miles, 20 miles, 1500 yards)
    - the intensity (e.g., 8 min/ml pace, 18 mph, moderate intensity, etc

Food/Activity Record

Name: ________________________________ **Date**: ________ **Day of Week**: M T W Th F Sa Su

(circle one)

Please record as accurately as possible all food and beverages you consumed for one day. Please give as many details as possible regarding the food/beverage item. Please list all supplements consumed including sports foods/beverages, vitamins, minerals, herbs etc. You may use the back if necessary.

Time	Food/Beverage	Brand or Source	Type of Preparation	Amount
8:00 am	Example: raisin bagel	Lenders	Toasted	1 ea. (3 oz)
9:00 am	Example: weight training	1 hour	moderate intensity	

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