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Prevalence of Low-Energy Availabilty Amongst Female Paralympic Athletes

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PREVALENCE OF LOW-ENERGY AVAILABILITY AMONGST FEMALE PARALYMPIC ATHLETES

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ABSTRACT

PREVALENCE OF LOW-ENERGY AVAILABILITY AMONGST

FEMALE PARALYMPIC ATHLETES

by

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The prevalence of low-energy availability (LEA) in able-bodied female athletes has been extensively examined; however, research has yet to examine LEA in Paralympic athletes. Therefore, the purpose of this study was to examine the risk of LEA and related symptoms including menstrual health, hormonal profiles, and bone mineral density (BMD) in female para-athletes. Female national para-athletes (n = 9) completed 7-day food and activity logs, Low Energy Availability in Females Questionnaire (LEAF-Q) and Eating Disorder Examination Questionnaire (EDE-Q), Dual energy X-Ray Absorptiometry (DXA) scans, and hormonal profile blood spot testing. LEAF-Q results suggested that 78% of athletes were considered “at-risk” for LEA, while energy availability calculations based on energy intake (EI) and exercise energy expenditure (EEE) suggested that none of the participants had LEA (< 30 kcal·kg $FFM^{-1}.day^{-1}$). Menstrual dysfunction was reported in four participants who were also taking hormonal contraceptives. Hormonal blood spot tests suggested that progesterone was low in 67% of the participants (2.1 $\pm$ 0.3 nmol/L), with no trends between those considered “at-risk” and “not at-risk” for LEA using LEAF-Q. Triiodothyronine (T3) and estradiol levels were within normal range for all participants. Insulin-growth factor (IGF-1) was elevated (>

13.1-39.2 nmol/L) in 22% of athletes. Five participants (56%) had clinically low BMD in the hip regional score (< -2 z-score), one of which reported a bone-related injury within the past year. Based on the LEAF-Q and DXA scans risk of LEA appears to be high; however, according to the EDE-Q and EA calculation risk of LEA appears to be low. This considerable discrepancy in the assessment tools suggests the need for further investigation using a larger sample size and a wide range of assessment tools to determine which are most effective for assessing energy availability in female para-athletes.

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I. INTRODUCTION

Low Energy Availability (LEA) was initially described in female athletes as the *Female Athlete Triad* (Triad). The Triad consists of three interrelated conditions including energy deficiency, low bone mineral density, and menstrual dysfunction (1, 2, 3). These conditions are each characterized on a spectrum ranging from optimal health to a disease state and range in symptoms and severity (2). In addition, any of these conditions may be experienced in solitude or in combination with one another to be diagnosed with the Triad. The Triad can lead to decreased athletic performance, increased risk for injury, and serious short and long-term health consequences. This highlights the need for early detection, diagnosis and treatment of these medical conditions amongst all female populations, particularly athletes (2, 4). While LEA had originally been seen as more common among the female athlete population, it became evident that "energy deficiency" also affects males as well. Therefore, an expansion of the Triad, referred to as *Relative Energy Deficiency in Sport (RED-S)*, was recently introduced to include a broader spectrum of health and performance outcomes and further aspects of physiological functioning that result from an energy deficiency in both men and women (5, 6). RED-S results in impaired physiological functioning of hormonal and reproductive pathways including menstrual health, bone mineral density, protein synthesis, metabolic rate, immunity, and cardiovascular health (5, 6).

EA is defined as energy intake (kcals) minus energy expended during exercise (kcals) divided by kilograms (kg) of fat-free mass (FFM). The amount of energy remaining after exercise energy expenditure is necessary to support basic metabolic and physiological functioning (7, 2). Thus, an athlete has low energy availability when they fail to consume sufficient energy to support the energy expended in exercise, as well as the energy needed to support basic metabolic functioning. Although discrepancies exist in the literature (8), the low energy availability threshold is recognized as < 30 kcal·kg FFM^{-1}.day^{-1} in adult able-bodied females (4). While this definition is well established in the able-bodied population, it may be inappropriately applied to para-athletes. Differences in active muscle composition, mobility, metabolic systems including the reduction in sympathetic nervous system in athletes with paralysis, and other injury-related factors affect the ability to determine the proper LEA threshold in para-athletes (1, 9, 10). In addition, para-athletes may have varying energy requirements, different factors influencing bone health, and menstrual function compared to the able-bodied population, making this research even more vital (1, 10).

Furthermore, para-athletes may have lower energy needs and intakes due to differences in body composition including a lower FFM and higher body fat (1). In a study comparing able-bodied and paraplegic subjects, fat free mass (FFM) and resting metabolic rate (RMR) were lower in the paraplegic group compared to the control subjects. However, after adjustments were made for FFM, RMR did not differ between the able-bodied and paraplegic groups, suggesting that metabolic activity may be similar for fat free mass components. Therefore, energy expenditure relative to muscle mass in the paraplegic population may similar to that of their able-bodied counterparts (9).

In para-athletes, bone mineral density (BMD) varies in comparison to the able-bodied population, making it difficult to determine the true cause of low BMD as it relates to energy availability. Specifically, skeletal loading is significantly reduced in some para-athletes, especially those with SCI, which can lead to disuse osteoporosis and osteopenia that directly causes a decrease in BMD compared to their able-bodied counterparts. Therefore, the effects of LEA on bone in para-athletes has yet to be determined and needs further investigation with the consideration of baseline effects of the athlete's underlying impairment (6). Menstrual dysfunction is another condition that leads to decreased BMD; however, the cause can be difficult to determine in the Paralympic population due to effects of the injury and trauma on the regulation of sex hormones. It is known that menstrual dysfunction can present itself in able-bodied athletes if they have LEA (< 30 kcal·kg $FFM^{-1}.day^{-1}$). However, there is limited research examining the effects of low energy availability on menstrual health in para-athletes, separate to the injury-related effects (10).

While research examining the prevalence of LEA has been extensively conducted in able-bodied female athletes, research has yet to examine para-athletes. Furthermore, current recommendations for able-bodied athletes may erroneously be applied to athletes with disabilities. As the Paralympic movement continues to grow, this research is warranted to provide assessment and treatment recommendations for the sports medicine team (physicians, trainers, coaches, dietitians, and other personnel), and coaches (1). Therefore, the purpose of this study was to examine the risk of low energy availability and related symptoms including menstrual health, hormonal disturbances, bone mineral density, and metabolic and physiological functioning amongst female Paralympic athletes.

II. LITERATURE REVIEW

Introduction

Paralympic sport originated from Dr. Ludwig Guttmann, a specialist in spinal injuries in Buckinghamshire, who used sport as an integral part of the treatment in paraplegic patients. From there, the exposure of para athletes and sport began, leading to the the first ever Paralympic games in 1960, held in Rome (11). Since this time, the Paralympic movement has expanded and grown exponentially into an internationally recognized elite sporting event that featured over 4300 athletes in the 2016 Summer Paralympic in Rio and a record number of athletes that competed in the 2018 Winter Paralympics (1, 6). This large increase in participation has necessitated the need for determining appropriate energy intake guidelines and reference ranges in order to ensure adequate energy availability for safe competition in sport. Additionally, further research will allow for early detection, diagnosis, and treatment of energy-deficient complications and issues to prevent injury and disordered eating behaviors.

Paralympic athletes include those that have one of the following impairments: spinal cord injury (SCI), cerebral palsy (CP), brain injury, amputation, spina bifida, visual impairment, and Les Autres (other impairments such as dwarfism). A review of literature was conducted between September 2018-January 2019 using a variety of different literature outlets: *PubMed*, *Journal of Sports Medicine*, *CWU Interlibrary Loan* (ILLIAD), and other sport nutrition-related journals. Topics that were searched included, bone mineral density (BMD), menstrual function, low energy availability (LEA), Paralympic athletes, SCI, energy intake (EI), exercise energy expenditure (EEE), and total energy expenditure (TEE) in relation to para athletes with various forms of impairment. Based on the limited research on this specific population, literature examining these topics in able-bodied athletes has been included as well.

Energy Intake

Adequacy of energy intake for training, body composition, growth and development is very important. Additionally, energy intake must be measured to determine whether an individual is experiencing an energy balance, deficiency, or excess energy as it relates to energy expenditure. One of the greatest challenges is recording energy intake accurately by means of self-reported measures (6). This unveils the issue of accurately assessing an athlete's energy status, as energy intake is a vital component of determining whether sufficient energy is available to support the cost of exercise and bodily functions needed for training and optimal performance. Additionally, this could lead to an inappropriate intervention for the athlete depending on if the athlete was found to have low-, moderate- or high- energy availability (12). Errors could exist in the form of participant underreporting or over-reporting of actual dietary intake, time period selected for the food record, variation amongst foods recorded, and inaccuracies of dietary analysis software programs that generate nutrient intake data.

In capturing dietary intake, different methods are available depending on the time, resources, and capabilities that are available to the researcher. Food frequency questionnaires (FFQ), dietary recalls, and food records are some of the most commonly used assessment methods in research. While FFQ's are of great use when assessing nutrient status, it doesn't provide information on timing of food, combinations of food at meals, and relies heavily on participant memory. Food records have been found to be the most preferred method for obtaining estimates of actual dietary intake (13). However, this method also presents the most room for error in participant reporting, specifically under-reporting, and accurately quantifying portion sizes of food, which can account for 10-45% variability in energy intake. Some studies have noted that the longer the period of food recording is, the greater the likelihood of recording fatigue (14). However, this may be less likely when using athletes that are familiar with the practice of intricate daily food recording of metrics around training (13).

In a study done by Braakhuis et al. (15), food entry was completed using found to be another major source of error when assessing self-reported intake. From selecting the appropriate food item, entering in an accurate measurement and obtaining the appropriate nutritional content of each food item, there was great room for potential inaccuracies. In this study, 53 sport dietitians were instructed to enter in the dietary intake from four 7-day food records, in which 3-5 dietitians would be assigned to each of the thirteen dietary records that were used in this study. After the coding and dietary assessment was generated, the statistical analysis found that the variability in nutrient intake between assessments for the same athlete was a direct result of different dietitians entering in the food log, indicating at times, substantial error associated with the coder.

Aside from variation between different "coders" inputting a food log into a dietary analysis program, there are also inaccuracies when food records are kept for shorter periods of time. Braakhuis et al. (15) also found that when 24-hour recalls were used to capture dietary intake versus a 3-day diet record, the variability was much greater in the 24-hour recall. However, there was a reduction in variability as the duration of the period of recording food was increased. This signifies the importance of capturing a larger period of time for food record analysis to ensure that the nutrient analysis is more representative and reflective of actual dietary intake for each athlete.

In para-athletes, many studies assessed dietary intake at training camps in which the food was prepared for the athletes and attainment of nutritional information for foods was more readily available. Krempien and Barr (16) assessed the nutritional status of 32 athletes with a SCI using two separate 3-day weighed food records to measure energy intake. One of those 3-days was during a training camp in which the food was prepared for athletes and the other 3-days once athletes returned home to get a more realistic depiction of typical dietary intake. There was no significant difference found between these recording periods. Intakes for the male and female athletes with a SCI in this study were comparable to recommendations for that of sedentary able-bodied individuals of comparable size and age. Women in this study reported an average consumption of 2,056 ± 458kcal/kg/day or 36 kcal/kg/day (2011). In another study examining intake and supplement use in Paralympic athletes, it was found that males consumed an average of 2,092 kcal/day while females consumed an average of 1,602 kcal/day (17). Therefore, these studies suggest that there is some variation amongst this population of athletes, even within the same sport. It is hypothesized that the differences in impairment and body weight play a role in these intake variations. Additionally, timing of the study and reporting measures can cause noted differences as training regimen and dietary patterns can vary from in-season to off-season training. Regardless of the differences that may exist, dietary references and recommendations currently only exist for able-bodied athletes. Little research has examined appropriate reference ranges for macronutrient and micronutrient intake for the para-athlete population (16). Therefore, further research is needed to examine energy needs for this population of athletes in order to determine the acceptability and adequacy of the para-athletes dietary intake that these other studies have reported.

Exercise Energy Expenditure

Exercise energy expenditure (EEE) is defined as the amount of energy expended during physical activity (PA) (18). There are various means by which EEE has been captured in order to provide an accurate depiction of the energy cost for different forms of exercise endeavors. Heikura et al. (19) tracked exercise performed throughout the day via self-reported activity logs in their study examining low-energy availability (LEA) in able-bodied elite distance athletes. Exercise mode, duration and intensity measured by heart rate or perceived exertion ratings were included to most effectively determine the extent of physical activity recorded. Heart rate is useful for measuring exercise intensity as it increases proportionally and linearly to oxygen uptake (19, 20). In order to quantify this activity, metabolic equivalents (METs) were assigned to each activity that corresponds to the type and intensity of that activity (19, 21). In a study examining energy availability, Melin et al. (4) also used training logs, heart rate monitors, and assigned METs to determine EEE in elite endurance athletes. METs have been used for the purpose of quantifying estimates of physical activity energy expenditure.

Para-athletes pose a greater challenge in assessing EEE due to the differences in body composition, physiological responses to exercise, and sympathetic nervous system (SNS) activity. The reduced muscle mass that results from loss of limb functioning results in a diminished ability for physical activity and leisure time. The type of impairment and level of spinal lesion will also determine the level of physiological system impairment as it relates to substrate utilization and energy expenditure in athletes with a SCI (22, 23). When testing VO2peak, athletes with a SCI had a lower peak output than their able-bodied counterparts (22). Additionally, athletes with tetraplegia had an even lower VO2 peak when compared with athletes with high and low level paraplegia on an incremental arm crank ergometer (22). These differences show that the EEE for any given exercise mode and intensity appears to be lower in athletes with SCI than able-bodied athletes. Additionally, the level and completeness of SCI appears to be important in determining the potential energy expenditure during PA. Therefore, a distinguishment must be made when quantifying EEE in para-athletes versus able-bodied athletes (23). When comparing EEE in athletes with paraplegia and able-bodied athletes during structured basketball, the mean EEE was 6.5 kcal/min and 10.0 kcal/min, respectively (24, 25). Additionally, comparing EEE in tetraplegic rugby players versus able-bodied athletes a great discrepancy was found of 4.2 kcal/min and 16.0 kcal/min, respectively (26). These studies suggest a significantly lower EEE in para-athletes than that of able-bodied athletes in these sports, along with tennis and other endurance sports (22).

While several physical activity compendiums have been developed for the general population of adults, wheelchair activities have formerly been excluded from such lists. In order to more accurately quantify EEE in wheelchair sports, Conger & Bassett (23) developed a comprehensive compendium of physical activity for wheelchair users with various impairments. Taking into account the differences in resting metabolic rate (RMR) and, thus, the definition of a MET value between able-bodied populations and wheelchair users, energy cost of activities were assessed using indirect calorimetry, and quantified with use of a body of previously published literature. A total of 63 different wheelchair activities were identified and EEE was quantified and compared to similar activities performed by able-bodied athletes. The energy cost of exercise, recreation activities, and sport were found to be consistently lower (average 27%) in individuals who use wheelchairs than that of the general population. While these findings can be used as a resource for coding physical activity, much of the data was collected on small populations. Therefore, precautions should be taken when using this compendium as the determination of EEE in this population. Additionally, energy expenditure can vary between individuals depending on specific injury and a variety of other physiological factors. The compendium compiled the average data for similar activities so that the values would be generally applicable to the all wheelchair users. Further considerations should be made when determining the energy cost of activities amongst this population (23).

Other methods that have been used to measure EEE in athletes with a SCI include: SenseWear Armbands (SWA), doubly labelled water (DLW), direct observation, accelerometers, and heart rate monitors (27). While there is currently no single "gold standard" for judging the validity of measurement tools for estimating PA, DLW has been considered the most accurate and precise method (28). However, depending on the specific population, accessibility to resources, form of physical activity, and research question the appropriate method for measurement may vary (22).

Doubly labelled water (DLW) is a technique that quantifies EEE via CO2 production by the difference in elimination of the two isotopes, 2H and 18O as body water and CO2. The SenseWear Armband (SWA) is a wireless activity monitor that quantifies EEE by integrating motion data from a 2-axis accelerometer and variables such as skin temperature, galvanic skin response, and heat flux. When these two methods were used to assess changes in energy expenditure in SCI athletes during periods of sedentary activity and physical activity, the results found that DLW was able to detect the changes in energy expenditure between the two periods only. SWA, however, could not detect the changes from sedentary activity to PA, thus underestimating EEE in this population. DLW was able to detect a 15% increase in energy expenditure in SCI athletes when going from sedentary activity to PA, suggesting that this may be a more sensitive and accurate method of measurement (28). In another study, when the SWA was worn by SCI athletes during physical activity alone, it was found to overestimate EEE. This overestimation is thought to be caused by the fact that the SWA manufacturer's algorithms and model are not based on the typical movements associated with wheelchair users in the predefined activity categories, rather able-bodied movements. Therefore, certain activities performed while wearing the SWA by wheelchair users are classified as being more strenuous than actual EEE (20, 28).

Accelerometers are another device that have been used to aid in measuring physical activity energy cost. These movement sensors report the progress of frequency and intensity of exercise in 'activity counts' per unit time. These monitors have been compared to a variety of criterion laboratory measurements in people who use wheelchairs measured by oxygen output and indirect calorimetry to demonstrate validity. The two most commonly used accelerometers in research pertaining to physical activity in wheelchair persons are uni-axial and tri-axial. The most commonly used accelerometer, tri-axial, includes movement in the anteroposterior, mediolateral, and vertical axes. These tri-axial monitors have been placed on the wheels of the wheelchairs or on the armrests. However, these positionings have been found to be flawed in estimating energy expenditure as they fail to predict moderate to intense physical activity during structured exercise and movement outside of the wheelchair (20). Some laboratories have placed accelerometers in parallel arrays at various anatomical locations to better monitor activity being performed. These monitors were primarily used for SCI and amputee populations, as well as those undergoing rehabilitation. These found to have 92% specificity and sensitivity; however, were found to be more obtrusive and burdensome to participants that wore them during the study. Additionally, these monitors were only able to be used for durations < 48 hours due to the memory and battery life, which does not keep with the current requirements for length of wear of PA monitors (20, 29). More precision can be gained if accelerometers are incorporated with self-report measures to understand specific personal and environmental barriers to exercise as are numerous for wheelchair athletes (20).

The physical activity behavior of individuals who use wheelchairs as their primary source of locomotion is inherently difficult to measure due to the heterogeneous nature of the population, whereby different disability aetiologies responsible for the use of a wheelchair result in highly variable movement patterns. Therefore, accuracy and validity of the chosen measurement should be taken into account when determining EEE in para-athletes (22).

Total Energy Expenditure/RMR

Total daily energy expenditure (TDEE) is the amount of energy expended throughout the entire day, comprised of the thermic effect of food (TEF), exercise energy expenditure (EEE), and resting metabolic rate (RMR) (9). It has been suggested that TEF accounts for approximately 3-10% of energy expended; RMR, the main determinant of energy expenditure, accounts for approximately 65% of TDEE; and physical activity accounts for the remaining energy expended. Many studies have shown that 70-85% of the variation in RMR is explained by fat-free mass (FFM) (9, 30, 28). TDEE has been extensively studied in various populations of able-bodied athletes to assess the differences in energy expenditure between sedentary and active individuals. Recently, studies have started to investigate the differences in TDEE, specifically the RMR, between para-athletes and able-bodied controls. It has been well understood that para-athletes of all injury levels have lower RMR levels and decreased EEE, resulting in an overall lower TDEE than their able-bodied counterparts. With diminished mobility and the physical limitations that exist for para-athletes, as well as the decreased FFM because of limb paralysis and inactivity, a lower TDEE is to be expected (9, 28). Additionally, some persons with SCI have a reduced sympathetic nervous system (SNS) available during exercise, subsequently reducing the peak physiological responses to that of their able-bodied counterparts. During a 24-hour testing period, resting metabolic rate values for those with SCI (C6-L3) have been reported ~1,879 kcal/day compared with ~2,365 kcal/day for able-bodied matched controls (22). However, studies differ in their explanations and conclusions for such results. The specific subject group of para-athletes, as well as the method of assessment between studies should be closely examined when comparing results.

Buchholz et al. (9) used indirect calorimetry and found that RMR was significantly higher (14%) in the control group than the paraplegic group, remaining significant when adjusted for age, weight, fat mass, and hormonal parameters. However, this difference was reduced to < 2% when adjusted for FFM. The best single predictor of RMR was FFM, which accounted for 83% of the variation in RMR in control subjects and 70% of the variation in paraplegics. These findings led to the conclusion that the metabolic activity of the fat-free body is similar in both able-bodied and paraplegic individuals, agreeing with the findings of Liusuwan et al. (31) that concluded there was no difference in RMR when adjusted for lean tissue mass (LTM) in children with SCI (2004). However, Pelly et al. (30) found that lean-tissue mass (LTM) in able-bodied versus paraplegic participants, expended less energy. Athletes with SCI, for instance, expended an average of 25 + 13 kJ/kg LTM more than able-bodied controls. The explanation for this was that the energy expended from LTM at rest is influenced by the metabolic activity of the viscera rather than skeletal muscle, thus, the level of injury greatly influences the result. In this specific study, the majority of para-athletes that were tested had a lesion lower than T10 which includes LTM from the lower extremities that likely contribute to a lower proportion of the REE. Therefore, considerations should be made in regards to the level of injury/lesions of the para-athletes included in studies examining TDEE and the influence of RMR as it relates to FFM/LTM (2017). In general, the higher the level of spinal cord lesion, the greater the loss of function (22). In a recent review, Broad and Juzwiak (32) suggested that the Cunningham equation is a suitable method for calculating RMR when indirect calorimetry is not available, in the para-athlete population as it provided the most accurate REE estimate when compared to indirect calorimetry.

When examining the differences in TEF between para-athletes and able-bodied counterparts, Buchholz et al. (9) found that there was no significant difference between the two groups. TEF was measured with indirect calorimetry for 120 minutes after the consumption of a mixed liquid meal consisting of 30% fat, 55% carbohydrate, and 15% protein. This is similar to other studies that found no significant difference between TEF in relation to TDEE in SCI athletes (33). Therefore, it can be concluded that with the current research on able-bodied and para-athletes, TDEE and RMR present the area of most variance between the two groups, largely related to differences in FFM and exercise capabilities. Further research is warranted in order to more accurately assess the energy expenditure of para-athletes.

Female Athlete Triad

The suggested cutoff values for low-energy availability in able-bodied individuals is < 30 kcal/kg body weight. There have been extensive studies conducted to better support this threshold as a diagnostic tool for determining energy status in athletes of all sports. However, no research has been performed in Paralympic athletes, therefore, this able-bodied threshold may not be applicable to this population of athletes regardless of the observable differences between the two. LEA has long been associated with a condition known as the Female Athlete Triad (Triad), coined in 1993 (34). The Triad has been characterized by three conditions including, LEA, low bone mineral density (BMD), and menstrual dysfunction or hypothalamic amenorrhea. These conditions were known to occur along a spectrum of optimal health to disease and may be experienced in solitude in conjunction with one another in a female athlete (6). In this syndrome, LEA was defined as being an energy deficit with or without disordered eating. Upon continuation of research, scientific evidence found that the aetiological factor underpinning the Triad was an energy deficiency relative to the balance between dietary energy intake (EI) and the energy expenditure required to support homoeostasis, health, activities of daily living, growth and sporting activities. Therefore, in 2007, the International Olympic Committee (IOC) expanded on the definition of the Triad by making the claim that this clinical phenomenon was not a triad inclusive to just three symptoms, but rather a syndrome resulting from relative energy deficiency, thus introducing a new term (1, 6).

Relative Energy Deficiency in Sport

Relative Energy Deficiency in Sport (RED-S), introduced by the International Olympic Committee, expands on the Female Athlete Triad and includes a broader spectrum of health and performance outcomes that result from an energy deficiency in both genders. In the IOC Consensus statement, RED-S was defined as, "impaired physiological function including, but not limited to, metabolic rate, menstrual function, bone health, immunity, protein synthesis, cardiovascular health caused by relative energy deficiency (6)." Other physiological functions associated with energy deficiency in RED-S include, endocrine, skeletal, hematological, gastrointestinal, and central nervous system alterations. Psychological disturbances, such as depression have also been found to be a cause of disordered eating and caused by LEA in athletes (6) While disordered eating is responsible for a large proportion of LEA cases, other unintentional causes include knowledge deficit in relation to energy needs in sport, inability to track energy intake (EI) and over-exercise. While prevalence varies across genders and sports, there has been minimal research efforts examining the the validity of the LEA threshold (< 30kcal/kg FFM) in the para-athlete population. Methodological differences must exist between studies done on able-bodied athletes and those done in the para-athlete population in order to account for differences in body composition related to injury/disability versus energy status. Additionally, these results necessitate the urgency that must be placed in further examining the prevalence in the para-athlete population to determine thresholds specific to this group for prevention and treatment guidelines to be constructed.

For example, in a study examining energy availability in endurance athletes, Melin et al. (35) used food and activity logs, heart rate monitors, questionnaires, bicycle ergometer, transvaginal ultrasound, and reproductive blood testing to determine prevalence of LEA amongst able-bodied athletes. Results found that 8 of the 40 participants were categorized into the LEA (< 30 kcal/kg FFM) category, while the remaining participants had optimal (N = 15) or reduced (N = 17) energy availability according to the measurements used (35). In para-athletes, BMD and reproductive function may not be measured and compared to similar reference values due to the effects of the athlete's injury or disability on those parameters, independent of energy status. Heikura et al. (19) also examined energy availability in elite distance runners with the purpose of investigating the RED-S and Triad diagnostic tools, while also providing a cross-sectional report on measurements assessing LEA. The methods included DXA scans, food/activity logs, blood plasma to test reproductive and metabolic function, and questionnaires assessing dietary behaviors. Results found that 37% of females presented with amenorrhea (AME) and low BMD and 40% of males had low testosterone (TES) (14.8 ± 3.6 nmol/L) according to the diagnostic tools. Additionally, self-reported records of food intake and activity logs showed that 25% of males and 31% of females had LEA (< 30kcal/kg FFM). The most significant finding from this study found that those same individuals with AME and low TES had 4.5x more training absences related to bone injuries due to LEA. While it was concluded that there are difficulties in measuring EA with 100% accuracy, these findings present further proof of the need for testing and determining appropriate prevention measures to ensure athletes are safely competing (19). The results from this study as well as the multitude of others done on able-bodied athletes present evidence that LEA is prevalent among elite and competitive athletes, further increasing risk of injuries during sport. Therefore, determining risk of LEA in this population is even more warranted in order to determine appropriate nutrient recommendations for these athletes to help reduce further risk of injuries during competition and training.

Disordered Eating

Disordered eating (DE) has been defined as irregular eating behaviors that may or may not warrant a diagnosis for a specific eating disorder, being more descriptive in nature. It has been established that LEA is caused by a discrepancy between an athlete's dietary intake and the amount of total energy expended during exercise and required to support basic physiological functioning for optimum health. This diminished energy intake has been found to be caused by intentional or unintentional calorie restriction (6). As current guidelines for total energy, carbohydrate, and fluid provisions are based on data from able-bodied athletes, there is a limited evidence base for nutritional recommendations specific to SCI and para-athletes (22). This makes it difficult to determine nutrient recommendations for this population, leading to a lack of resources and knowledge imparted into para-athletes regarding appropriate energy intake to sustain optimal performance. Additionally, there is limited research regarding eating attitudes and behaviors of para-athletes as a whole (36). For this reason, unintentional causes of disordered eating or energy deficiency amongst this population of athletes is an anticipated risk. However, there is also reason to believe that intentional disordered eating amongst para-athletes is an even greater risk due to the psychological consequences of their injury or disability, as well as the fear of gaining weight due to an increased focus on weight control. Additionally, the presence of constraining physical impairments may cause an athlete to manipulate energy intake to ensure that they comfortably fit in their sport chair and can perform at the optimum performance level that is desired (1).

Eating Behaviors and Attitudes

Eating behaviors vary greatly between individuals, dependent on nutrition knowledge, access to food, physical mobility to purchase and prepare food, and attitudes about dietary intake and weight. In a study assessing dietary intake of Canadian SCI athletes, it was found that macronutrient and micronutrient consumption was adequate for the majority of nutrients. With the exception of fiber and sugar intake, SCI athletes met the majority of recommendations pertaining to energy intake to support energy expenditure. However, this study noted the fact that these recommendations are for able-bodied individuals and may not be appropriate reference ranges for those with physical impairments, such as those with SCI. When comparing energy intake across genders, it was also found that female SCI athletes had a significantly lower energy intake than the male SCI athletes of comparable age, injury, and activity level (17). Goosey-Tolfrey et al. (37) also found that male wheelchair athletes had significantly higher energy (2060 + 904 vs. 1520 + 342 kcal) and protein (90 + 29 vs. 64 + 17g) intakes compared with their female counterparts of similar mean physical characteristics. The average of the male and females’ energy intake as a group was also found to be 40% less than the recommendations for their able-bodied counterparts (2010). While it is known that para-athletes have a decreased energy expenditure compared to these athletes, these decreased intake behaviors should draw attention and be further examined to determine if para-athletes have a greater restriction to dietary intake (6).

In a study done on elite athletes with SCI in Canada, eating behaviors and attitudes were examined using a self-reported food log, anthropometric data, and the Three Factor Eating Questionnaire (TFEQ). These methods were used to better assess cognitive dietary restraint, hunger, and disinhibition in these athletes. Cognitive dietary restraint has been defined as being intentional monitoring of food and beverage intake by an individual in attempts to manipulate and control energy intake to achieve a desired body composition. There have been no other reported studies that have examined this in SCI athletes. Results found that the cognitive dietary restraint scores for men were significantly higher than those for women, while the disinhibition and hunger scores were lower. Krempien and Barr (16) noted that these scores represent a unique behavior among the male SCI athletes reflecting cognitive dietary restraint with a low susceptibility to hunger and satiety cues than that of their able-bodied counterparts. Females had similar restraint scores as those of young women; however, only 3 females were represented in this study. Conclusions drawn from these results show the many factors that greatly affect eating behaviors and attitudes surrounding food for SCI athletes, and the reality that dietary restraint to achieve desired body weight may be a trend (2012). While there is still extensive research that needs to be done to examine eating behaviors and attitudes of para-athletes, considerations of this dietary restraint should be made when assessing needs of para-athletes.

Other reasons that may lead to intentional dietary restriction in para-athletes include the desire to comfortably fit within their sport chair or prosthetics and to maintain functional mobility that excessive weight gain may disallow. In terms of knowledge surrounding nutritional requirements and energy intake specific to this population, the lack of resources and reference values set may lead to unknowingly consuming inadequate nutrition. Lastly, physical setbacks such as, difficulty swallowing, inability to purchase and prepare food independently, and food aversions caused by medication or physiological disturbances may all be factors that can alter this populations intake patterns (36, 32). Because the nutrient density of food choices needs to be optimal for these athletes to meet their recommended vitamin and mineral intakes, a closer evaluation of the dietary choices available to athletes at national-team events is warranted.

Questionnaires that Assess LEA Risk

Many questionnaires have been created over the years to identify risk factors, behaviors, and attitudes that are representative of disordered eating and symptoms associated with LEA, aside from clinical evaluation only. The Low Energy Availability in Females Questionnaire (LEAF-Q) was designed specifically for female athletes to assess physiological symptoms of energy deficiency including reproductive function, gastrointestinal health, menstruation, and bone health. A study was done on 84 Swedish athletes in order to evaluate the use of this screening tool for qualitative use in research. Results found that the LEAF-Q had an acceptable sensitivity, specificity, and internal consistency, indicating that it is a useful screening tool in the identification of female athletes at risk for energy deficiency and associated symptoms of LEA (35). Since then, further studies have used the LEAF-Q to assess risk of energy deficiency in a variety of sports. Heikura et al. (19) used the LEAF-Q to assess self-reported amenorrhea for their study examining low energy availability in female elite runners. Athletes were grouped into eumenorrheic and amenorrheic categories based on reproductive functioning. The results showed a significantly higher LEAF-Q score, indicating higher risk of LEA in the amenorrheic group versus the eumenorrheic group, denoting the sensitivity of the LEAF-Q in identifying reproductive function. The authors concluded that qualitative screening tools may provide a more accurate representation of an athlete's long-term energy availability status and the more sensitive way to diagnose LEA than measuring EA using self-reported intake logs (2018).

Greater difficulty has been found in identifying a screening tool to assess risk factors associated with LEA in para-athletes, specifically. Type of injury, date of onset, and use of contraceptives are all factors that would need to be considered when assessing menstrual function and BMD in this population. However, eating behaviors and attitudes for para-athletes may be motivated be factors specific to their injury, such as, concern of fitting into sport chair/prosthesis or discomfort of eating before training or competition. Therefore, screening tools for able-bodied athletes may not be as effective by itself in this unique population of athletes. These considerations should be addressed when determining a screening tool to best assess eating behaviors and attitudes, menstrual function, and bone mineral density in the para-athlete. Krempien and Barr (36) chose to use the three-factor eating questionnaire (TFEQ), a 51-item scale, in order to assess eating behaviors in SCI athletes. The TFEQ is used to assess three different aspects of eating attitudes and behaviors associated with food including, cognitive dietary restraint, disinhibition, and hunger. This scale was chosen based on the findings that the TFEQ restraint scale has good internal consistency and test-retest reliability with good stability over a 12-month period (38). However, there remains doubt regarding the number and nature of the specific dimensions within this questionnaire, and thus, has not been used as frequently as other screening tools in more recent studies (38).

A questionnaire that has been deemed an instrument of choice and gold standard in identifying eating disorder behaviors, is referred to as the eating disorder examination questionnaire (EDE-Q). This tool is a comprehensive assessment of specific disordered eating attitudes and behaviors that is appropriate in length for use in self-report measures. In comparison to the eating disorder inventory (EDI), which was thought to be a more comprehensive assessment, the EDE-Q was determined to be more appropriate and validated as a screening tool due to the length (39). The EDE-Q has four subscales including dietary restraint, eating concern, weight concern, and shape concern. The average score of each subscale is determined. A score of > 4 is deemed "at-risk," while scores < 4 are considered "not at-risk" for eating disorder behavior. The questions within this questionnaire are applicable to both the able-bodied and para-athlete population; however, further research is needed to determine specificity, reliability, and validity of the EDE-Q in the para-athlete population. Additionally, there is limited evidence for the efficacy of all self-reported questionnaires, therefore, considerations should be made when using these qualitative screening tools to determine risk of LEA (6).

Bone Mineral Density

Low bone mineral density (BMD) is commonly associated with energy deficiency and puts female athletes, specifically, at increased risk for osteopenia and osteoporosis. In addition, low bone mineral density can increase the risk of bone related injuries such as bone and stress fractures, especially in athletes. According to the ACSM (18), low BMD is defined by z scores between -1.0 and -2.0 with the presence of other risk factors. The International Society for Clinical Densitometry (ISCD) defines abnormal BMD as being < 2.0 for all able-bodied pre-menopausal women and males. In the para-athlete population, however, there have not been established thresholds defining low BMD in relation to injury or impairment. In individuals with SCI, regardless of activity level, disuse osteopenia/osteoporosis is common due to reduced skeletal loading over time. Females in general are at greater risk for low BMD due to the progressive decline in bone mass associate with estrogen loss after menopause. Therefore, in female para-athletes, these two factors lead to particular vulnerability for diminished bone health and increased risk for low energy fracture (1). While exercise has been shown to increase BMD in the able-bodied population, the effect of exercise on para-athletes has been examined minimally. It is known that BMD loss occurs until the end of 1 or 2 years post-injury and does not return to normal in these athletes; however, higher BMD scores have been found in upper extremities of para-athletes versus their able-bodied counterparts (40).

In a study examining male wheelchair basketball players, Goktepe et al. (40) compared paraplegic athletes to paraplegic sedentary subjects in order to examine the effects of physical training on BMD in these paraplegic athletes. DXA scans of the radius, hip, and spine were assessed in order to determine site specific impacts. Results found an increase in BMD in the lumbar region of the athletes; however, not significant. In the proximal femur region, both groups were found to have reduced BMD, which supports literature stating that the femur isn't exposed to direct stress during physical activity in a wheelchair. Higher BMD scores in the radius were found in both groups; however wheelchair players had significantly higher BMD's than sedentary paraplegic subjects. These results coincide with the results of Jones et al. (41) comparing physically active individuals with SCI to their healthy counterparts and finding that SCI subjects had higher arm BMD values. Additionally, the lumbar region was found to be normal in both groups, while the proximal femur region was lower in SCI athletes. The findings in Goktepe et al. (40) support similar findings in which BMD of the legs, trunk, and entire body in wheelchair athletes that return to sports activity after injury were higher than those that delayed physical activity. However, other studies have suggested that physical activity (wheelchair basketball) was not associated with a better preserved bone density below the injury level when compared to sedentary SCI patients (40, 1).

Osteoporosis was found to be present in 100% of SCI individuals within the paralyzed extremities (42). One study aimed at examining the effects of physical activity on BMD and whether these activities play a role in the prevention of osteoporosis in male SCI athletes. Among subjects there were no significant differences in BMD based on level of injury, sport, and age. In arms, BMD (g/cm2) was greater in wheelchair athletes than AB athletes (0.856 + 0.050, 0.896 + 0.056, respectively); however, significantly lower BMD was found in legs of wheelchair (WC) athletes (WC: 1.052 + 0.179, AB:1.373 + 0.091). The period since injury was found to be negatively correlated with BMD in legs ($r = -0.549$, $P < 0.01$), body trunk ($r = -0.414$, $P < 0.05$), and whole body (r

= -0452, P < 0.05). Conversely, the earlier the individual returned to sport after injury, the higher the BMD in legs, body trunk, and entire body. This study concluded that the early sports rehabilitation regularly following the injury is useful in preventing bone loss in wheelchair athletes with SCI (43).

Aside from physical activity, research has also examined the impact of micronutrient intake on BMD in athletes with SCI. Calcium and vitamin D are micronutrients associated with bone health and have been found to be diminished in the diet of SCI athletes (36). In a study examining Vitamin D status and effects of supplementation on SCI athletes, Pritchett et al. (44) found that only 26% of participants had sufficient Vitamin D status at the beginning of the study. Once the supplementation intervention was started, the protocol resulted in a 167%, 66% and 21% increase in 25(OH)D concentrations in athletes that were deficient, insufficient, and sufficient, respectively. Over half of these participants were found to have improved handgrip strength once levels were restored as well. Whether or not that has a direct effect on BMD in these athletes has yet to be examined; however, some research has reported that low Vitamin D status is associated with increased incidence of decreased bone density (44). Furthermore, there have been no studies conducted on female para-athletes who have been hypothesized to be at greater risk for low BMD and greater risk of osteoporosis, due to their injury or impairment. In para-athletes, BMD will largely depend on baseline effects of of the individual's underlying injury or disability, therefore, considerations should be made when determine LEA based on BMD in this population (6). The research conducted in para-athletes as it relates to BMD points to the need for reference standards and diagnostic criteria to be specified for this population in order to assess risk of LEA.

Menstrual Function

Low energy availability has been found to play a causal role in menstrual dysfunction induced by over-exercise and undernutrition. Originally seen as one of the components of the female athlete triad, menstrual dysfunction has been found to be directly affected by energy availability, and in turn, directly influences bone health (1). It is well documented that menstrual dysfunction can have negative health consequences including increased risk of the number of cardiovascular risk factors and premature osteopenia and osteoporosis (3). Menstrual dysfunction has been identified as the development of oligomenorrhea, primary amenorrhea, or secondary amenorrhea. Oligomenorrhea is defined as nine or less menstrual periods in one-year, primary amenorrhea refers to the first menstrual period beginning at > 15 years of age, and secondary amenorrhea being the cessation of menses for > 3 months. However, these definitions are those determined for able-bodied athletes only (1). Athletes that experience amenorrhea have also been found to have a lower energy availability than that of eumenorrheic athletes and non-athletic controls. The probability of developing menstrual dysfunction as energy availability dropped below 30kcal/kg FFM was found to be around 50% (45). While menstrual health has been largely examined in able-bodied athletes, there is a paucity of research in the para-athlete population surrounding the effects of exercise-induced menstrual dysfunction. Due to the nature of the disability or injury in the para-athlete population, menstrual function may vary from the norms of the general athlete and may be multifactorial and related to the disability itself, training changes due to the nature of adaptive sports competition, or both (1).

The majority of the research that has been performed on SCI athletes in regards to the effects of the disability or injury on menstruation has concluded that there are no significant long-term effects regarding reproductive function in these individuals. In fact, many women with SCI have had successful and healthy pregnancies, while those with complete quadriplegia have reported fewer pregnancies than those with incomplete paraplegia that began in adulthood (1, 46). Amenorrhea was present in 41% of women in a retrospective study in SCI individuals; however, in the majority of these cases, it was transient amenorrhea lasting an average of 7.96 + 10.9 months, comparable to findings from another study in which menstruation resumed in an average of 5-months post-injury (1, 47). Of those women that were amenorrheic, 10 of the 53 participants in this study were able to conceive and carry out healthy pregnancies. The results found that pregnancy rate was significantly higher in women who experienced the injury at a younger age, while level of injury did not seem to draw correlations with duration of amenorrhea or occurrence of pregnancy (47). However, it should be noted that these studies did not include the athlete cohorts from this population of individuals, which present heightened consequences given the greater energy expenditure and potential LEA in athletes versus sedentary SCI individuals (1).

Elevated prolactin levels, known as hyperprolactinemia, have been found to affect the pattern of menstruation in the general population of women. Elevated prolactin levels are normal in pregnant women, especially following birth so that milk production occurs and the baby can feed; however, has also been found in women with SCI following injury. Prolactin has been thought to be elevated in the acute phase of SCI injury due to its proposed importance in coping with stress and trauma. In a study examining the effects of hyperprolactinemia on amenorrhea in this population, it was found that SCI women with amenorrhea also had the highest levels of prolactin, proposing a possible correlation with hyperprolactinemia and amenorrhea. Authors concluded that acute amenorrhea (6-month period post trauma) following SCI is due to a transient increase in prolactin as part of the neurochemical response to the stressful situation (48).

The use of oral contraceptives (OCs) and hormonal contraceptives (HCs) has also been an under-researched area of interest as it related to menstrual function and hormonal markers in athletes. Research has indicated that 40.2% of Norwegian athletes and 27.6% of American athletes use OCs. Some of the proposed reasons have included the difficulty in having a menstrual cycle during sport competition and the correlated side-effects that exist with menstruation. Martin et al. (49) studies the prevalence of these contraceptives and their effects on the menstrual cycle in elite athletes. Results found that HC use in elite athletes (45.6% with 69% being combined with OCs) was significantly higher than that of the general population in the United Kingdom. Nearly one third of combined OC users were able to manipulate menstruation length and frequency in attempts to avoid it during training or competition periods to diminish the negative side-effects associated (2018). These results from able-bodied elite athletes point to a potential concern of this same behavior amongst the Paralympic population. Due to the added difficulties in mobility and discomfort experienced by para-athletes, the desire to manipulate and control timing and duration of cycle may be heightened in this population. Additionally, when testing for LEA in this population, the use of OCs should be considered as hormonal parameters may be skewed depending on the specific OC used.

Hormonal Function

The effects of LEA on hormonal functioning is an area that has been studied extensively in able-bodied athletes. Heikura et al. (19) examined these effects on both male and female elite distance athletes to assess the extent to which LEA contributes to altered hormone levels. In males, it has been found that low testosterone (TES) and metabolic hormone have been correlated in athletes with LEA; however, not below the clinical range. Therefore, Heikura et al. (19) obtained blood samples for insulin, TES for males, estradiol (E2) for females, triiodothyronine (T3), and insulin-like growth factor (IGF-1). Results found that of males with low TES, 60% were found to have had a history of > 2 stress fractures. Additionally, females that were amenorrheic and males with low TES were found to have significantly lower sex hormone and T3 concentrations compared with eumenorrheic and normal TES participants (19). When participants were characterized as “high-risk” based on the RED-S and the Triad cumulative assessment tools, significantly lower T3 concentrations were also seen in both genders. This is in line with findings from Loucks et al. (34) who concluded that LEA is the main reason for the suppression of metabolic and reproductive function in females. In a more recent study, it was found that reciprocal effects have been seen in males as well. Tenforde et al. (50) reported that many studies performed on elite endurance-trained male athletes have found a 40% reduction in TES and 43% reduction in sperm counts following “overtraining,” compared with baseline values.

RED-S, referred to as, "impaired physiological functioning caused by relative energy deficiency," has shown to have potential harmful hormonal effects associated with the aetiological factor of LEA. Many studies looking at female athletes in LEA states have found decreases in insulin and IGF-1, alterations in thyroid function, and elevations in cortisol. Much of this has been explained by the body's need to conserve the limited energy available for the important bodily functions or to use as energy reserves for vital processes, thus, disallowing for energy needed for hormonal and reproductive functions (6). In a study examining the dose-response relationship between energy availability and markers of bone turnover in menstruating women, it was found that estradiol was unaffected by energy restriction until the restriction became severe (< 20 kcal/kg FFM/day). Additionally, IGF-1, T3, and leptin declined significantly at energy availability < 30 kcal/kg FFM in these females; however, approached an asymptotic limit at < 20 kcal/kg FFM compared with values at 45 kcal/kg FFM, which represents a balanced energy availability. LH pulsatility was also abruptly disrupted at a threshold of energy availability < 30 kcal/kg FFM, referred to as LEA. Thus, these findings show that a dose-response relationship may exist between metabolic and reproductive hormones and energy availability (51).

Koehler et al. (52) examined effects of alterations in short-term EA manipulation through diet and exercise on hormonal parameters in 6 male habitual exercisers. LEA was not found to significantly affect T3, testosterone, or IGF-1 levels; however, did reduce leptin and insulin levels compared to baseline. However, the relationship between LEA state and disruptions to endocrine function in both male and female athletes is largely variable and likely to be subject to within- and between- participant variability with more research needed (6). Additionally, endocrine and hormonal reference ranges specific to individuals with paraplegia in all its forms is needed as this population may have alterations based on impairment or injury in addition to differences in energy availability.

Currently, ranges for metabolic and reproductive hormones have only been established for able-bodied individuals. According to the *American Board of Internal Medicine* (53), current reference values are as follows: estradiol (F) 10-180 pg/mL, (M) 20-50 pg/mL; progesterone (F-follicular) .02-.9 ng/mL, (F-luteal) 2-30 ng/mL, (M) .12-.3 ng/mL; testosterone (F) 18-54 ng/dL, (M) 291-1100 ng/dL; SHBG (F) 18-144 nmol/L, (M) 10-57 nmol/L; cortisol (8am) 5-25 ug/dL, (4pm) < 10 ug/dL; IGF-1 (Ages 16-24) 182-780 ng/mL, (Ages 25-39) 114-492 ng/mL; fT3 2.3-4.2 pg/mL. These reference ranges are used in clinical settings of various sorts based on a wide array of research and literature (2019). However, clinical cutoffs may not be applicable for elite athletes of any sort in assessing LEA (19). Therefore, considerations should be made when comparing and assessing metabolic and reproductive hormone levels of able-bodied and para-athletes.

Conclusions

Paralympic athletes are a population of individuals that have very unique and differing energy requirements dependent upon the nature of the injury or impairment and the different levels of exercise and training involved in para-sports. Additionally, BMD, menstrual functioning, dietary intake, and hormonal parameters can be drastically altered in comparison to their able-bodied counterparts because of the impairment. Able-bodied athletes have been researched and examined extensively in regards to energy availability and the effects of LEA on these various body processes. However, very minimal research has been performed on para-athletes as it relates to energy intake and the effects of this energy availability on reproductive, metabolic, and skeletal processes. The prevalence of LEA in the Paralympic population has not been examined and para-athletes could potentially be at great risk for the various implications associated with LEA as discussed in this review. As this population of athletes continues to grow and expand worldwide, it is imminent that standards be set specific to the nature of the injuries or impairments. Currently, standards and reference ranges for able-bodied athletes may be erroneously applied and used for para-athletes, making it difficult to actually assess these individuals accurately.

Future research is needed to examine the differing energy requirements, micronutrient and macronutrient intake, for para-athletes based on exercise expenditure, additional supplementation needed for injury or impairment, and specific nutrients that are lacking in their diet. Additionally, more accurate research in a controlled environment is needed to better assess the caloric intake and energy expenditure of these athletes. Much research has examined these two factors based on self-report measures and the assignment of METS; however, many inaccuracies exist in these methods so greater specificity is needed to more accurately determine energy availability. BMD is another area in which no reference ranges exist for para-athletes in regards to z-scores and fracture risk. Studies with larger sample sizes of para-athletes are needed to determine an average BMD reference range from DXA scan results. Metabolic and reproductive hormone reference ranges have also not been established for the para-athlete population, making it difficult to determine the actual effects of energy availability on reproductive function. In conclusion, much more research is needed in this growing population of athletes to determine effects of LEA on various physiological functions and determine reference values and standards that can be used for diagnostic and treatment purposes for Paralympic athletes.

III. METHODS

Participants

Participants were recruited by word of mouth and emails sent to the coaches of various para- national, and collegiate level teams. Eleven para-athletes ($\geq$ 18 years old) from the US Olympic Committee (USOC) Paralympic program, Canadian Institute of Sport as well as the wheelchair basketball and track teams at the University of Illinois were recruited for this study. Inclusion criteria were as follows: presence of a physical disability, and the use of a wheelchair as the sole form of locomotion. Exclusion criteria included subjects who were currently pregnant, experiencing menopause or were post-menopausal and/or had current injuries preventing them from engaging in their normal training. Participants were informed about the study design before signing an informed consent. Approval for this study was granted by Central Washington University Human Subjects Review Committee.

Study Design

In a descriptive study design taking place at a training camp at the University of Illinois Urbana-Champaign (Urbana, IL) and Daytona Beach, FL, questionnaires, blood testing, body composition, and bone density measures were collected from each participant on the day of testing. Responses were scored and analyzed to determine overall risk of low energy availability components, including menstrual health, bone mineral density, and energy availability based on dietary intake and physical activity logs.

Dietary Intake and Training logs

Dietary intake and activity was recorded by participants for seven consecutive days. Participants were instructed to maintain their typical dietary habits and training during the seven days. Participants were provided education via a training video by a registered dietitian nutritionist (RDN) educating subjects on how to complete the food log, including details regarding portion sizes, timing, and detailed descriptions of food items consumed. The video included both verbal and visual instructions for completing the food log. Upon completion of the food journal, the RDN reviewed the food journals and had an opportunity to clarify any questions pertaining to food portions/intake from subjects. The RDN then entered all food intake for each participant into a nutrient analysis software program (Elizabeth Stewart Hands and Associates (ESHA Food Processor), Salem, OR). Daily energy (kcals) and macronutrient (carbohydrates (grams), fiber (grams), protein (grams), and fat (grams)) intake over the seven days were analyzed using ESHA Food processer.

Energy Expenditure was assessed using an activity diary undertaken simultaneously with the food diary and was analyzed in conjunction with energy intake to assess energy availability. The process used for calculating EA is shown in Table 1 based on Heikura et al. (19).

Table 1: Method for assessing EA based on food/activity logs (EI – EEE)/ FFM = EA

Energy Intake (EI)	• 7-day consecutive food log completed by all participants to reflect dietary intake most representative of typical diet. • Household weights, scales, and measures used to record accurate portions sizes of meals (instructions included within food/activity log) • Training video educating participants how to properly complete food log and importance of being precise • RDN estimated total EI by analyzing food logs with dietary analysis software (ESHA).
Exercise Energy Expenditure (EEE)	• Estimate EEE using 7-day training log where exercise description, training duration, and intensity is recorded. Athletes encouraged to maintain normal routine during this time. • Assign each exercise endeavor and training an energy cost (kcals/kg/hr) using a compendium of activities performed by wheelchair users, that represents the intensity and type of that activity (Conger & Bassett 2011). • Multiply the energy cost for each training session by the duration of the session to yield EEE. • REE was found using the Cunningham prediction equation and divided by 24 to get hourly REE (Cunningham, 1991). • Subtract REE from tEEE so that only the additional energy cost of exercise is included in the EEE • Use this EEE value in the equation above
Energy Availability (EA) cutoff values	• Low EA: < 30 kcal·kg $FFM^{-1}.day^{-1}$ • Moderate EA: 30-45 kcal·kg $FFM^{-1}.day^{-1}$ • Optimal EA: > 45 kcal·kg $FFM^{-1}.day^{-1}$
Fat-free mass (FFM)	• Fat-free mass was obtained from DXA scans.

Note: METs = metabolic equivalents, tEEE = total EEE. [Table adapted from Heikura, I.A., Uusitalo, A.L.T., Stellingwerff, T., Bergland, D., Mero, A.A. and Burke, L.M. (2018). “Low Energy Availability Is Difficult to Assess but Outcomes Have Large Impact on Bone Injury Rates in Elite Distance Athletes.” *International Journal of Sport Nutrition and Exercise Metabolism* 28(4): 403-411.]

Questionnaires

Participants completed the Low Energy Availability in Females Questionnaire (LEAF-Q). This questionnaire gathers information from subjects regarding their injuries, gastrointestinal and reproductive function. Specifically, it is comprised of thirty items distributed around six areas which include injuries and illness over the last year, dizziness, cold sensitivity, gastrointestinal function, and past and present menstrual dysfunction (35). Test-retest reliability was found to be 0.79 within a two week timespan (35). Participants who score $\geq$ 8 are considered at risk for the Triad while participants scoring < 8 are considered low risk. In the present study, the LEAF-Q was used to determine risk of low-energy availability based on this scoring system. This tool has been validated for correctly identifying energy availability, reproductive function and bone health in endurance female athletes and thus is an appropriate tool to be used when screening athletes for the Triad (35).

Bone Mineral Density and Anthropometrics

Participant's weight was measured to the nearest 0.1 kg using a modified digital scale in which participants sat directly on the scale for measurement. Athletes were instructed to wear loose-fitting, lightweight indoor clothing with no metal or reflective material and no shoes. Length was measured with subjects in a supine positon on a firm surface with the participant's soles of their feet against the wall. The measured length was verbally reported to the participant and if the measurement differs by more than 2 cm than what the subject believed her height to be, the measurement procedure will be repeated.

Dual energy X-ray absorptiometry (DXA) (General Electric, Lunar iDXA) was used to assess fat-free, fat and bone mass. The scans performed included a whole body scan, a lumbar/femur scan, as well as a hip scan on each participant to determine bone mineral density (BMD) at these various sites. These sites have been chosen in order to differentiate the whole body BMD from other key sites, as para-athletes may present with a normal whole body z-score, regardless of a low hip or lumbar BMD. Z-scores calculated using a reference database for an able-bodied population as there are currently no references for individuals with spinal cord injury. This test was performed in the morning with subjects in fasted and resting states. The subjects lay on the scanning table and remained stationary during the several one-minute scans. DXA testing was performed by a DXA specialist who has been trained in radiology. DXA is considered a precise measurement and the gold standard for determining BMD (2, 54). Radiation exposure is low for DXA compared to other x-rays (55). All participants were also given pre-testing instructions for the DXA scan to certify that requirements for an accurate scan was adhered to and to further inform the athlete on the procedure of the scan.

Menstrual Function

If a participant suspected that they were pregnant, a pregnancy test was administered to the athlete at the start of testing. A component of the LEAF-Q is aimed at addressing and assessing reproductive function in these female athletes. Subjects were asked to identify menstrual patterns and history such as age of menarche, current or past menstrual irregularities, and number of menstrual cycles during the year. The questionnaire also identified if the subject was currently using forms of birth control which may influence menses. A pre-screening form was also administered to participants prior to receiving the questionnaires, to further address menstrual status. Participants answered questions regarding use of oral contraceptives and dietary behaviors influenced by comfort and performance during sport.

Blood Samples

Blood samples were obtained using a finger stick to examine whole blood for estradiol, T3 and IGF-1. Estradiol is the primary female sex hormone. T3 is a thyroid hormone, which can be responsible for menstrual irregularities. Insulin-like Growth Factor (IGF-1) is also a hormone in which irregular levels may indicate menstrual dysfunction. The blood spot method was used to analyze each of these hormonal parameters. This method has been shown to provide valid and reliable data with the following correlation value: IGF-1 ($R = 0.88$), T3 ($R = 0.82$), and estradiol ($R = 0.86$). The blood spot test was sent to ZRT Laboratories (Beaverton, OR) to be analyzed. Phase of the menstrual cycle was noted but not controlled for in this study.

Disordered Eating Behaviors

The Eating Disorder Examination Question (EDE-Q) version 6.0 was used to assess the eating behaviors of all subjects. This is a self-reported version of the original Eating Disorder Examination (EDE) which requires a structured clinical interview by a trained professional. The EDE-Q widely used in clinical and research settings worldwide (56). The self-questionnaire assesses the behaviors and attitudes related to disordered eating and eating disorders over the last 28 days. The questionnaire consists of 4-subscales including dietary restraint, eating concern, weight concern, and shape concern. There are 22 attitudinal questions that can be rated 0-6 by the participant. The EDE-6 is scored in the same way as the EDE. Scores are determined by summing the ratings from all questions pertaining to a specific subscale and then dividing it by the total number of items within the subscale. To find the overall score, all of the subscale sums are totaled up and then divided by the value of four which is the total number of subscales. According to the recommendations from the EDE interview, a mean global score of 4.0 has been used to identify disordered eating. However, there is evidence suggesting that subjects may have a global score lower than 4.0 and still be diagnosed with an eating disorder (56). For the present study, this scoring system was applied. Participants with a global score of $\geq$ 4 were classified as "at-risk" and those with scores of < 4 classified as "not at-risk" for disordered eating behaviors. Test-retest reliably has been found to be between 0.81-0.94 (57).

Subject's results were kept confidential. Subjects' names were initially linked with their results. This allowed researchers to inform the subject if they may be at increased risk for disordered eating and to provide the appropriate medical referrals for further assessment. This was performed in a confidential setting. Once all subjects had been informed of their increased risk, researchers removed the names of subjects from any data and identified subjects by a coded number system only. This ensured that no identifiable information was saved with the data. Referral information was offered to all subjects regardless of risk, and outside referrals were made by the USOC as necessary.

Statistical Analysis

Data were reported as mean $\pm$ standard deviation (SD) for dietary intake, blood measures, BMD, and calculated EA and all were reported descriptively. BMD was quantified via: Z > -1, normal BMD, Z $\leq$ -1, a trend for low BMD; and Z < -2, clinically low BMD. Frequencies were used to describe percentage of athlete's "at risk" for LEA using the LEAF -Q and LEA calculations. Further statistical analysis was not warranted with the data that was collected. The significance was set at $p < .05$.

IV. RESULTS

N = 9 para-athlete participants completed the study. Two participants were excluded due to inconclusive DXA scans and incomplete dietary intake and exercise logs, therefore, eight participants' data were reported. Descriptive characteristics including body composition, exercise energy expenditure (EEE) and dietary intakes are displayed in Table 2. Energy intake (kcal) and macronutrient (carbohydrate, protein, fat and fiber) intake, as well as EEE and EA are averages for the 7-day period.

Table 2. Participant (*n* = 9) descriptive characteristics and dietary and training data

	Participants								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Age (years)	27	29	21	32	24	19	24	25	41
Height (in)	64	51	57	59	64	56	54	64	70
Weight (kg)	44.0	36.8	42.0	42.3	54.5	55.1	34.1	57.0	64.5
Injury level	T-12	T-4	T-10	L1-L2	L2-L3	L3-L4	L-5	T-11	N/A
Years Injured	22	29	18	32	19	19	24	15	7
Body Fat (%)	29.0	20.3	31.6	34.3	39.7	34.5	33.6	37.3	28.2
Energy (kcals/day)	1661	2026	1807	1679	1286	1975	1263	1941	2168
CHO (g/kg/day)	4.6	4.5	2.8	4.4	2.3	3.6	4.2	3.9	3.9
PRO (g/kg/day)	1.9	3.7	2.7	1.7	1.3	1.6	1.3	1.9	1.6
Fat (% kcal/day)	34	43	47	36	39	41	34	29	33
Fiber (g)	30	24	9	17	21	15	10	21	22
LEAF-Q score	3	15	12	9	8	2	9	12	12
EEE (kcals/day)	110	78	113	41	191	580	40	233	549
EA ($kcal \cdot kg\, FFM^{1}.day^{-1}$)	49	67	59	59	33	40	54	49	41

Note. Values are presented as means ± SD. CHO = Carbohydrate; PRO = Protein; LEAF-Q = Low Energy Availability in Females Questionnaire (35); EEE = Exercise Energy Expenditure; EA = Energy Availability.

Dietary Intake and Exercise Energy Expenditure

Participants consumed an average of 1951 ± 724 kilocalories. For carbohydrate (CHO) intake, 22% of athletes consumed below the recommended intake range of 3-12 g/kg/day for athletes, while the overall average CHO intake of all participants fell within the lower-end of the range (3.8 ± 0.8 g/CHO/kg/day). Protein intake was adequate amongst this group of athletes (2.0 ± 0.8 g/kg/day), with all athletes consuming within or above the recommended intake range (1.2-2.0 g/kg/day) (58). Fiber intake amongst this population was below the recommended intake range for females (25-35g/day) with only one participant falling within the recommendation and an overall average intake of 19 ± 7 g/day.

Exercise energy expenditure varied between participants based on sport, training days, and season periodization. Using Conger & Bassett's compendium of energy costs for individuals that use wheelchairs (23), the average energy cost from exercise expenditure was 215 ± 208 kcal/day, showing a wide variance between participants. The sports represented in this study track & field (n = 7) and basketball (n = 2).

Energy Availability

Calculated EA using energy intake and exercise energy expenditure was computed for each day and averaged over the 7-day period (Table 1). No participants were found to have LEA according to EA cutoff values (< 30 kcal·kg^{-1} FFM^{-1}.day^{-1}), three participants were considered to have moderate EA (30-45 kcal·kg FFM^{-1}.day^{-1}), while the remaining participants (n = 6) had optimal EA (> 45 kcal·kg FFM^{-1}.day^{-1}) according to reported intake and exercise. The average EA amongst this population was 50 ± 11. However, daily fluctuations of EA existed for each participant, with some participants having a calculated EA of < 30 kcal·kg FFM^{-1}.day^{-1} during the 7 days, signifying LEA. Nevertheless, average EA for all days were reported in order to get a more comprehensive and accurate depiction of EA for each athlete.

Qualitative Questionnaires

LEAF-Q scores suggested that 78% of participants were "at-risk" (11 $\pm$ 2) while the average overall score also represented an "at-risk" score (9 $\pm$ 4) for LEA based on menstrual history and physiological symptoms of insufficient energy intake. The EDE-Q suggested that one subject was "at-risk" for disordered eating behavior according to the four subscales within: *Restraint, Eating Concern, Shape Concern, and Weight Concern*. The overall average EDE-Q global score was 1.7 $\pm$ 2.0. The subscale that the participant scored lowest in was, "shape concern," while the highest subscale score was in, "dietary restraint." However, that participant was considered "not at-risk" according the LEAF-Q score and had optimal EA according to EA calculation involving dietary intake, exercise energy expenditure and fat-free mass.

BMD and Reproductive/Metabolic Function

Eight participants (89%) reported current birth control use. Menstrual dysfunction was reported in four participants (45%) who were also taking hormonal contraceptives. Menstruation in these individuals was identified as being inconsistent, irregular, and/or cessation of menstruation for $\geq$ 6 months.

BMD, reproductive and metabolic hormone levels are summarized for each participant in Table 3. Two participants had insufficient blood to analyze metabolic parameters. Reproductive profiles suggested that progesterone was low according to the reference range for the premenopausal luteal phase (< 10.5-71.6 nmol/L) in 67% of the participants (2.1 $\pm$ 0.3 nmol/L), with no trends between those considered "at-risk" and "not at-risk" for LEA according to LEAF-Q. However, menstrual cycle phase was unaccounted for in this study and, therefore, these participants may have been within normal limits depending on the specific phase each was in at time of blood collection.

Triiodothyronine (T3) and estradiol were within normal range for all participants. Insulin-like growth factor (IGF-1) was elevated (> 13.1-39.2 nmol/L) in 22% of athletes, with those identified as "not at-risk" according to LEAF-Q being within normal limits. The overall average IGF-1 for this group was 32.1 $\pm$ 11.3 nmol/L.

Three DXA scans were attempted on all participants including whole body, lumbar (spine), and hip/femur scans. The spinal scans were not usable, as most subjects had metal rods in this region making it difficult for the software to distinguish between bone and metal, thus skewing the results for whole body scans as well. Therefore, hip z-scores were reported for all participants. There was two participants (22%) with a score of $Z > -1$, indicating normal BMD, and two participants (22%) with a BMD trending towards low ($Z \leq -1$). Five participants (56%), however, had clinically low BMD in the hip regional score ($Z < -2$ z-score), one of which reported a bone-related injury within the past year.

Table 3. Metabolic and reproductive hormone concentrations, bone density, and energy availability for each participant.

	Participants								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Reproductive									
Estradiol (pg/mL)	55	12	54	49	21	35	56	13	101
Progesterone (nmol/mL)	0.7	0.7	0.8	0.6	0.5	0.6	11.7	7.1	15.6
Metabolic									
IGF-1 (nmol/L)	35.3	34.3	20.3	27.8	53.7	31.2	25.6	43.2	17.3
T3 (pg/mL)	2.5	2.5	3.4	2.6	2.7	3.3	2.6	3.2	3.2
Bone Characteristics									
Whole body BMD (g/cm^2)	0.9	1.0	1.5	1.3	1.4	1.0	0.9	0.9	1.1
Hip z-score	-2.2	-2.7	-1.0	-0.1	-2.1	-0.9	-3.3	-2.4	-1.6
Injury level	T-12	T-4	T-10	L1-L2	L2-L3	L3-L4	L5	T-11	N/A

Note. Values are presented as means $\pm$ SD. IGF-1 = insulin- like growth factor; T3 = triiodothyronine; N/A = not available; BMD = bone mineral density; z-score = age-matched reference value for BMD; EA= energy availability; FFM = fat-free mass. BMD reference values: $Z < -2$, clinically low; $Z \leq -1$, trend for low; $Z > 1$, normal [9].

V. DISCUSSION

This is the first study to examine the risk of low energy availability and related symptoms including: menstrual health, hormonal disturbances, bone mineral density, metabolic and physiological functioning, and nutrient intake amongst female national level Paralympic athletes. The primary findings suggest that prevalence of EA varied depending upon the assessment tool used to determine risk or presence of LEA amongst this population. Based on EA calculation and EDE-Q, risk of LEA appears to be low, while based on LEAF-Q and DXA scans, risk of LEA appears to be high. Qualitative and quantitative measures showed considerable discrepancies that must be considered when interpreting the results.

Assessing energy intake accurately presents many opportunities for error. Heikura et al. (19) examined EA among elite able-bodied (AB) male and female distance runners and suggested that calculated EA via dietary and exercise recording is challenging and lacking in sensitivity as a diagnostic tool for the presence of LEA (19). While food records have been found to be the most preferred method of obtaining estimates for actual dietary intake, it also presents the most room for error in participant reporting, specifically under-reporting, and inaccurately quantifying portion sizes of food which may account for 10-45% variability in energy intake (14). Additionally, this could lead to an inappropriate nutrition intervention for the athlete depending on whether the athlete was found to have low-, moderate- or high- energy availability (12). However, this may be less likely when using athletes that are familiar with the practice of intricate daily food recording of metrics around training (13). In the present study, specificity of dietary intake and training throughout the day and exact measurements varied between participants, with some providing details of each food item and portion size, and others providing vague and indefinite descriptions and measurements. Conger & Bassett (23) provide the only known compendium of energy costs for individuals using wheelchairs. Therefore, the exercise mode in the compendium that most closely resembled that of which was recorded during training was used to estimate exercise energy expenditure for each participant. Despite these challenges in self-reporting, clarifying questions were asked to each participant by the investigator in order to most accurately assess intake (portion sizes, food brands, ingredients used in prepared meals, etc.) and expenditure in order to provide strong estimations that could be used to determine energy availability. When examining the EA calculated from self-reported food and training logs, two participants were considered to have moderate EA (30-45 $kcal \cdot kg\ FFM^{-1}.day^{-1}$), while the other six participants were considered to have optimal EA (> 45 $kcal \cdot kg\ FFM^{-1}.day^{-1}$). While extensive research has been conducted in AB elite athletes, this is the first study to examine EA in Paralympic athletes. Heikura et al. (19) found that 11 female participants had LEA and 24 females had moderate EA, while no females had optimal EA when using calculated EA. The authors also found that measured EA was poorly correlated with other factors known to be associated with LEA including reproductive, metabolic, and bone health. While the current study didn't employ correlations due to the small sample size, no trends were observed among the participants with moderate EA versus optimal EA as it related physiological symptoms associated with LEA. These results are similar to other studies that also failed to find an association between dietary EA and physiological indices of LEA in female athletes (35, 52).

The average caloric intake of participants within this study was 1951 ± 724 kcals/day. This is very similar to findings from a study by Krempien and Barr (16) assessing 32 Canadian athletes with SCI, of which 8 were female, using two separate 3-day food records to determine dietary intake. Average caloric intake of the females when eating at a training camp was 2,056 ± 458 kcals/day, while average intake when recording food consumed at home was 1,927 ± 510 kcals/day. While no significant differences were found in dietary intake between these females at training camps versus at home, these results show a similar caloric intake as was found from the female para-athletes from the current study. In another study examining supplement use and intake in Paralympic athletes, it was found that females consumed an average of 1,602 kcals/day, which is slightly less than the present study (17). It can be seen that there is a range of variation amongst this population and has been hypothesized that differences in injury, body weight and disability play a role in these intake variations. Additionally, training regimens and dietary patterns can vary from in-season to off-season and between individuals (16, 17).

One participant met the fiber intake recommendation for females aged 18-50 years old according to the Dietary Guidelines for Americans (25-35 g/day) in this para-athlete population, while the remainder fell below (58). The average intake amongst the group was 19 ± 7 g/day. While other AB studies examining energy availability found greater fiber intake among individuals that were amenorrheic or had disordered eating behavior, there was no correlation to that found within this study as 89% of participants had inadequate fiber intake already (19, 59). One proposed reason for this increase in fiber intake among female athletes is thought to be for the appetite suppression effect that fiber can have on an athlete's appetite when consumed, decreasing caloric intake typically. Additionally, in AB studies, active females have been found to have low energy density diets, high in water-rich foods such as fruits and vegetables, high in fiber, and low in fat (59). However, this was not a trend found in this study.

The current study suggested that progesterone was low in 67% of participants, while estradiol was within normal limits for each participant. However, phase of the menstrual cycle was not controlled for at the time of the blood spot test, therefore, lower values for progesterone could be explained by fluctuations of this hormone throughout the cycle. In a study examining, relationship between energy availability and markers of bone turnover in menstruating women, estradiol was not affected by energy restriction until the restriction became severe (< 20 kcal·kg $FFM^{-1}.day^{-1}$), which is consistent with our findings as no participants had severe energy restriction (51). IGF-1 was elevated in 25% of participants, while T3 was within normal limits in the current study. Loucks and Thuma (51) found that IGF-1 and T3 significantly declined at an energy availability threshold of < 30 kcal·kg $FFM^{-1}.day^{-1}$; however, approached an asymptomatic limit at < 20 kcal·kg $FFM^{-1}.day^{-1}$. The cause of elevation of IGF-1 in two of our participants was unidentifiable and unspecified. It should be noted that the reference ranges used to compare hormonal and metabolic parameters were based on an able-bodied population. These clinical cutoffs may not be applicable for elite athletes in assessing LEA, including Paralympic athletes as these athletes are all very different as it relates to specific injury, sport and energy needs (19). In addition, the relationship between EA status and disruptions to endocrine function in both male and female athletes is subject to within- and between- participant variability with more research needed (6).

Menstrual function in this group was abnormal for four of the participants (44%) ranging in reasons that were unspecified to cessation of menses for $\geq$ 6 months. Of those with menstrual abnormalities, one participant had primary amenorrhea (cessation of menses for $\geq$ 3 months), two participants had secondary amenorrhea (cessation of menses for $\geq$ 6 months), and one participant also stated that menstrual changes were noticed relative to training load (bleed fewer days, menstruation ceasing, etc.). However, 89% of participants in this study were using some form of hormonal contraceptive, with only one participant reporting no use. In AB athletes, research has indicated that of 430 elite athletes, 49.5% were using hormonal contraceptives and 69.8% had used them at some point. Proposed reasons for this use was related to difficulty in having a menstrual cycle during certain training and competition periods, along with the associated side-effects that exist with menstruation. Elite athletes were also able to manipulate menstruation length and frequency in attempts to avoid it during training or competition to diminish the adverse side-effects (49). These menstrual concerns in AB athletes are only further amplified in Paralympic athlete population due to the added difficulties of mobility. Therefore, menstruation patterns should be examined carefully, as abnormal menstruation and hormonal parameters are likely masked by contraceptive use within these athletes.

Whole body, hip, and spine scans were chosen in order to get an overall depiction of BMD in the different regions within these athletes. BMD was quantified via: $Z > -1$, normal BMD; $Z \leq -1$, a trend for low BMD; and $Z < -2$, clinically low BMD (60). In this study, whole body scans and spine scans were inconclusive as the placement of metal equipment skewed the scores and made the data unreliable for all participants. Therefore, the hip region was the most accurate scan to assess BMD; however, it was limited to just one region and gave only a partial depiction in these athletes. Five participants (56%) had clinically low hip BMD (Z < -2) one of which reported a bone-related injury within the past year, and wo participants had a BMD trending towards low ($Z \leq -1.0$). Remarkably, only two of the three participants with moderate EA (lowest in the sample) had low hip BMD based on these z-scores. In contrast, Melin et al. (35) reported only 5% of elite, AB female athletes that had low BMD in the hip region, while 45% of female athletes had impaired bone health overall. Another study examining effect of sport on BMD in male wheelchair athletes found that BMD was related to the time period since injury, with lower BMD found in those with a longer period since injury. Thus, the earlier return to sport following injury also promoted increase in BMD in those athletes (43).

Therefore, when assessing BMD values in relation to low-energy availability in the para-athlete population, it is important to decipher whether low BMD is an indicator of LEA risk or rather a factor of impairment in these athletes. Previous studies performed in this population have found correlations between lower BMD in areas most affected by the SCI, indicating a probable higher association between BMD and injury rather than LEA (40, 43). Therefore, given that low BMD is common in most individuals with SCI, regardless of diet quality or energy intake, diagnostic criteria may need to be altered when assessing risk of LEA in para-athletes.

In the two questionnaires used as qualitative measures for determining risk for LEA, within subject variability was present. According to the LEAF-Q, 78% of participants were "at risk" for LEA based on a score ≥ 8. While no other known studies that have used the LEAF-Q in para-athletes, Heikura et al. (19) found that LEAF-Q scores differed in eumenorrheic and amenorrheic AB athletes. Amenorrheic individuals had an average score of 8.3 ± 3.7 while eumenorrheic individuals had an average score of 12.8 ± 4.8. This significantly higher LEAF-Q score in the eumenorrheic group led authors to conclude that LEAF-Q was an appropriate tool for assessing risk of the Female Athlete Triad. This supported the findings from a previous study done on 84 Swedish athletes to assess the effectiveness of this screening tool. Results found that LEAF-Q had an acceptable sensitivity, specificity and internal consistency, considering it to be a useful tool in the identification of females at risk for energy deficiency and associated symptoms of LEA (35). However, no trends existed between estimated energy availability and LEAF-Q scores in the current study. The differences in risk factors associated with LEA in female para-athletes make it difficult to use screening tools, such as LEAF-Q in identifying risk of LEA. Menstrual history and function, contraceptive use, and GI function assessed on this screening tool may be more related to the injury, rather than actual LEA. Therefore, the LEAF-Q should be used with caution with this population of athletes. While menstrual dysfunction was largely related to higher risk scores, it was largely the result of injuries related to overuse of the upper body in para-athletes rather than bone-related injuries, and contraceptives that cease menstrual cycles for a duration of time.

In contrast to the LEAF-Q, the EDE-Q results found only one participant to be at-risk for disordered eating and potential LEA in this study. While it doesn't directly determine risk of low energy availability, this questionnaire has been considered an instrument of choice when identifying behaviors surrounding eating disorders. Out of the four subscales within the EDE-Q, participants scored highest in the "shape concern" category. While an average global score of ≥ 4 is deemed at-risk for eating disorder behavior, the average score amongst our participants were 1.8 ± 2.0 showing great variability and a low risk for these behaviors in this para-population. However, when asked if participants restricted caloric intake due to concern of fitting into sport chair or due to discomfort that may be felt when eating before activity, five participants reported restricting due to discomfort before activity, while three reported restricting due to concern of fitting into sport chair. This was an interesting finding based on the low EDE-Q scores that assess risk of disordered eating behaviors. Mond et al. (61) used this tool in a large sample of women from Australia, aged 18-42 years. Similar to our study, the mean global score for all subscales was 1.5 ± 1.3, with the highest subscale score in the "shape concern" category. Another study involving a community-based sample of young women found a mean global score of 0.9 ± 0.8, with the highest subscale score also being "shape concern" (62). In the para-athlete population specifically, this higher score regarding body weight or shape could have also been attributed to concern of fitting into their sport chair during competition, as that was a mentioned concern of participants within this study. This small sample size makes it difficult to determine the effectiveness of this tool within this population, therefore, more research is needed to determine whether this tool is useful for para-athletes.

Limitations

The most practical limitation of this study was the small sample size. Only 9 participants completed the study, which may not be representative of the status of female Paralympic athletes. However, the heterogeneity of this population in terms of impairment should be noted. Other limitations included the use of self-reported food logs, as they were vague in some instances, without precise portion size measurements recorded. Exercise descriptions were difficult to quantify using the Conger & Bassett (23) compendium of energy costs of physical activities. Training sessions included a variety of different activities that were not included in the compendium, therefore, the most comparable activity was used to quantify each exercise in order to report an estimate of EEE.

When examining blood spot tests for hormonal and reproductive functioning, participants were unable to clearly define what phase they were in due to the contraceptive devices and / or sporadic nature of their menstrual cycle. This made it difficult to determine whether they were within or outside of the range for estradiol and progesterone. Using only one region (hip) out of the three DXA scans performed to determine BMD didn't give the most accurate depiction of each participants' bone characteristics in the various parts of their body, specifically around the site of injury or impairment.

VI. CONCLUSIONS

Considerable discrepancies existed between the results from the questionnaires and EA calculations in assessing risk of low-energy availability. Additionally, quantitative screening tools, such as the DXA scan and blood spot tests used in this study, may be difficult to use as diagnostic measures when assessing LEA with this population. Studies that use DXA to examine the bone characteristics of para-athletes should consider the sources of error that may obscure the integrity of the BMD measurements. This study concluded that when calculating EA based on dietary intake and EEE, no LEA existed within this group of female para-athletes. However, a greater risk for LEA was suggested when using BMD and results from LEAF-Q to determine risk. With very limited studies assessing EA in para-athletes, there is a lack of assessment tools specific to para-athletes that isolate symptoms merely associated with LEA (63). Therefore, further research and screening tools validated specifically for this population is warranted in order to better determine the energy availability of Paralympic athletes.

Practical Applications

Low energy availability is a concern in female athletes. The International Olympic Committee (IOC) have recognized the impacts of energy status on physiological processes and support the that energy deficiency may contribute to menstrual dysfunction, impaired bone health, reproductive and hormonal imbalance, and more. With differing energy requirements, bone health, and menstrual function, the ability to identify LEA may require different assessments. This study shows the difficulty of using screening tools created for AB athletes for para-athletes. The variations in this population may be multifactorial and attributable to the characteristics of the disability itself, differences in training due to the nature of adaptive sports competition, or a combination of both. Nevertheless, there is a need for more screening tools that can help to distinguish between symptoms associated with LEA rather than the injury in order to more accurately determine prevalence of LEA in this population.

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