AMERICAN COLLEGE of SPORTS MEDICINE®

ACADEMY OF NUTRITION AND DIETETICS
DIETITIANS OF CANADA

Nutrition and Athletic Performance

JOINT POSITION STATEMENT

ABSTRACT

It is the position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine that the performance of, and recovery from, sporting activities are enhanced by well-chosen nutrition strategies. These organizations provide guidelines for the appropriate type, amount, and timing of intake of food, fluids, and supplements to promote optimal health and performance across different scenarios of training and competitive sport. This position paper was prepared for members of the Academy of Nutrition and Dietetics, Dietitians of Canada (DC), and American College of Sports Medicine (ACSM), other professional associations, government agencies, industry, and the public. It outlines the Academy's, DC's and ACSM's stance on nutrition factors that have been determined to influence athletic performance and emerging trends in the field of sports nutrition. Athletes should be referred to a registered dietitian/nutritionist for a personalized nutrition plan. In the United States and in Canada, the Certified Specialist in Sports Dietetics (CSSD) is a registered dietitian/nutritionist and a credentialed sports nutrition expert.

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This joint position statement is authored by the Academy of Nutrition and Dietetics (AND), Dietitians of Canada (DC), and American College of Sports Medicine (ACSM). The content appears in AND style. This paper is being published concurrently in *Medicine & Science in Sports & Exercise®* and in the *Journal of the Academy of Nutrition and Dietetics*, and the *Canadian Journal of Dietetic Practice and Research*. Individual name recognition is reflected in the acknowledgments at the end of the statement.
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This paper outlines the current energy, nutrient, and fluid recommendations for active adults and competitive athletes. These general recommendations can be adjusted by sports dietitians to accommodate the unique issues of individual athletes regarding health, nutrient needs, performance goals, physique characteristics (ie, body size, shape, growth, and composition), practical challenges and food preferences. Since credentialing practices vary internationally, the term "sports dietitian" will be used throughout this paper to encompass all terms of accreditation, including RDN, RD, CSSD, or PDt.

This Academy position paper includes the authors' independent review of the literature in addition to systematic review conducted using the Academy's Evidence Analysis Process and information from the Academy Evidence Analysis Library (EAL). Topics from the EAL are clearly delineated. The use of an evidence-based approach provides important added benefits to earlier review methods. The major advantage of the approach is the more rigorous standardization of review criteria, which minimizes the likelihood of reviewer bias and increases the ease with which disparate articles may be compared. For a detailed description of the methods used in the evidence analysis process, access the Academy's Evidence Analysis Process at https://www.andevidencelibrary.com/eaprocess.

Conclusion Statements are assigned a grade by an expert work group based on the systematic analysis and evaluation of the supporting research evidence. Grade I = Good; Grade II = Fair; Grade III = Limited; Grade IV = Expert Opinion Only; and Grade V = Not Assignable (because there is no evidence to support or refute the conclusion). See grade definitions at www.andevidencelibrary.com/.

Evidence-based information for this and other topics can be found at https://www.andevidencelibrary.com and subscriptions for non-members are purchasable at https://www.andevidencelibrary.com/store.cfm.

EVIDENCE-BASED ANALYSIS

This paper was developed using the Academy of Nutrition and Dietetics Evidence Analysis Library (EAL) and will outline some key themes related to nutrition and athletic performance. The EAL is a synthesis of relevant nutritional research on important dietetic practice questions. The publication range for

TABLE 1. Evidence analysis questions included in the position statement Refer to http://www.andevidencelibrary.com/ for a complete list of evidence analysis citations.

EAL Question	Conclusion and Evidence Grade
Energy Balance and Body Composition	
#1: In adult athletes, what effect does negative energy balance have on exercise performance?	In three out of six studies of male and female athletes, negative energy balance (losses of 0.02% to 5.8% body mass; over five 30-day periods) was not associated with decreased performance. In the remaining three studies where decrements in both anaerobic and aerobic performance were observed, slow rates of weight loss (0.7% reduction body mass) were more beneficial to performance compared to fast (1.4% reduction body mass) and one study showed that self-selected energy restriction resulted in decreased hormone levels. **Grade II- Fair**
#2: In adult athletes, what is the time, energy, and macronutrient requirement to gain lean body mass?	Over periods of 4 to 12 weeks, increasing protein intake during hypocaloric conditions maintains lean body mass in male and female resistance-trained athletes. When adequate energy is provided or weight loss is gradual, an increase in lean body mass may be observed. **Grade III- Limited**
Recovery	
#3: In adult athletes, what is the effect of consuming carbohydrate on carbohydrate and protein-specific metabolic responses and/or exercise performance during recovery?	Based on the limited evidence available, there were no clear effects of carbohydrate supplementation during and after endurance exercise on carbohydrate and protein-specific metabolic responses during recovery. **Grade III- Limited**
#4: What is the effect of consuming CHO on exercise performance during recovery?	Based on the limited evidence available, there were no clear effects of carbohydrate supplementation during and after endurance exercise on endurance performance in adult athletes during recovery. **Grade III- Limited**
#5: In adult athletes, what is the effect of consuming carbohydrate and protein together on carbohydrate and protein-specific metabolic responses during recovery?	• Compared to ingestion of carbohydrate alone, coingestion of carbohydrate plus protein together during the recovery period resulted in no difference in the rate of muscle glycogen synthesis. • Coingestion of protein with carbohydrate during the recovery period resulted in improved net protein balance post-exercise. • The effect of co-ingestion of protein with carbohydrate on creatine kinase levels is inconclusive and shows no impact on muscle soreness post-exercise. **Grade I- Good**
#6: In adult athletes, what is the effect of consuming carbohydrate and protein together on carbohydrate and protein-specific metabolic responses during recovery?	Co-ingestion of carbohydrate plus protein, together during the recovery period resulted in no clear influence on subsequent strength or sprint power. **Grade II- Fair**
#7: In adult athletes, what is the effect of consuming carbohydrate and protein together on exercise performance during recovery?	Ingesting protein during the recovery period (post-exercise) led to accelerated recovery of static force and dynamic power production during the delayed onset muscle soreness period and more repetitions performed subsequent to intense resistance training. **Grade II- Fair**
#8: In adult athletes, what is the effect of consuming protein on carbohydrate and protein-specific metabolic responses during recovery?	Ingesting protein (approximately 20 g to 30 g total protein, or approximately 10 g of essential amino acids) during exercise or the recovery period (post-exercise) led to increased whole body and muscle protein synthesis as well as improved nitrogen balance. **Grade I- Good**
Training	
#9: In adult athletes, what is the optimal blend of carbohydrates for maximal carbohydrate oxidation during exercise?	Based on the limited evidence available, carbohydrate oxidation was greater in carbohydrate conditions (glucose and glucose + fructose) compared to water placebo, but no differences between the two carbohydrate blends tested were observed in male cyclists. Exogenous carbohydrate oxidation was greater in the glucose + fructose condition vs. glucose-only in a single study. **Grade III- Limited**
#10: In adult athletes, what effect does training with limited carbohydrate availability have on metabolic adaptations that lead to performance improvements?	Training with limited carbohydrate availability may lead to some metabolic adaptations during training, but did not lead to performance improvements. Based on the evidence examined, while there is insufficient evidence supporting a clear performance effect, training with limited carbohydrate availability impaired training intensity and duration. **Grade II- Fair**
#11: In adult athletes, what effect does consuming high or low glycemic meals or foods have on training related metabolic responses and exercise performance?	In the majority of studies examined, neither glycemic index nor glycemic load affected endurance performance nor metabolic responses when conditions were matched for carbohydrate and energy. **Grade I- Good**

Evidence Grades: Grade I: Good; Grade II: Fair; Grade III: Limited; Grade IV: Expert Opinion Only; Grade V: Not Assignable.

the evidence-based analysis spanned March 2006–November 2014. For the details on the systematic review and methodology go to www.andevidencelibrary.com. Table 1 presents the evidence analysis questions used in this position paper.

NEW PERSPECTIVES IN SPORTS NUTRITION

The past decade has seen an increase in the number and topics of publications of original research and review, consensus statements from sporting organizations, and opportunities for qualification and accreditation related to sports nutrition and dietetics. This bears witness to sports nutrition as a dynamic area of science and practice that continues to flourish in both the scope of support it offers to athletes and the strength of evidence that underpins its guidelines. Before embarking on a discussion of individual topics, it is valuable to identify a range of themes in contemporary sports nutrition that corroborate and unify the recommendations in this paper.

1. Nutrition goals and requirements are not static. Athletes undertake a periodized program in which preparation for peak performance in targeted events is achieved by integrating different types of workouts in the various

cycles of the training calendar. Nutrition support also needs to be periodized, taking into account the needs of daily training sessions (which can range from minor in the case of "easy" workouts to substantial in the case of high quality sessions (eg, high intensity, strenuous, or highly skilled workouts) and overall nutritional goals.

2. Nutrition plans need to be personalized to the individual athlete to take into account the specificity and uniqueness of the event, performance goals, practical challenges, food preferences, and responses to various strategies.
3. A key goal of training is to adapt the body to develop metabolic efficiency and flexibility while competition nutrition strategies focus on providing adequate substrate stores to meet the fuel demands of the event and support cognitive function.
4. Energy availability, which considers energy intake in relation to the energy cost of exercise, sets an important foundation for health and the success of sports nutrition strategies.
5. The achievement of the body composition associated with optimal performance is now recognized as an important but challenging goal that needs to be individualized and periodized. Care should be taken to preserve health and long term performance by avoiding practices that create unacceptably low energy availability and psychological stress.
6. Training and nutrition have a strong interaction in acclimating the body to develop functional and metabolic adaptations. Although optimal performance is underpinned by the provision of pro-active nutrition support, training adaptations may be enhanced in the absence of such support.
7. Some nutrients (eg, energy, carbohydrate, and protein) should be expressed using guidelines per kg body mass to allow recommendations to be scaled to the large range in the body sizes of athletes. Sports nutrition guidelines should also consider the importance of the timing of nutrient intake and nutritional support over the day and in relation to sport rather than general daily targets.
8. Highly trained athletes walk a tightrope between training hard enough to achieve a maximal training stimulus and avoiding the illness and injury risk associated with an excessive training volume.
9. Competition nutrition should target specific strategies that reduce or delay factors that would otherwise cause fatigue in an event; these are specific to the event, the environment/scenario in which it is undertaken, and the individual athlete.
10. New performance nutrition options have emerged in the light of developing but robust evidence that brain sensing of the presence of carbohydrate, and potentially other nutritional components, in the oral cavity can enhance perceptions of well-being and increase self-chosen work rates. Such findings present opportunities for intake during shorter events, in which fluid or food intake was previously not considered to offer a metabolic advantage, by enhancing performance via a central effect.
11. A pragmatic approach to advice regarding the use of supplements and sports foods is needed in the face of the high prevalence of interest in, and use by, athletes and the evidence that some products can usefully contribute to a sports nutrition plan and/or directly enhance performance. Athletes should be assisted to undertake a cost-benefit analysis of the use of such products and to recognize that they are of the greatest value when added to a well-chosen eating plan.

THEME 1: NUTRITION FOR ATHLETE PREPARATION

Energy Requirements, Energy Balance and Energy Availability

An appropriate energy intake is the cornerstone of the athlete's diet since it supports optimal body function, determines the capacity for intake of macronutrient and micronutrients, and assists in manipulating body composition. An athlete's energy intake from food, fluids and supplements can be derived from weighed/measured food records (typically 3–7 day), a multi-pass 24-hour recall or from food frequency questionnaires.[1] There are inherent limitations with all of these methods, with a bias to the under-reporting of intakes. Extensive education regarding the purpose and protocols of documenting intakes may assist with compliance and enhance the accuracy and validity of self-reported information.

Meanwhile an athlete's energy requirements depend on the periodized training and competition cycle, and will vary from day to day throughout the yearly training plan relative to changes in training volume and intensity. Factors that increase energy needs above normal baseline levels include exposure to cold or heat, fear, stress, high altitude exposure, some physical injuries, specific drugs or medications (eg, caffeine, nicotine), increases in fat-free mass and, possibly, the luteal phase of the menstrual cycle.[2] Aside from reductions in training, energy requirements are lowered by aging, decreases in fat free mass (FFM), and, possibly, the follicular phase of the menstrual cycle.[3]

Energy balance occurs when total Energy Intake (EI) equals Total Energy Expenditure (TEE), which in turn consists of the summation of basal metabolic rate (BMR), the Thermic Effect of Food (TEF) and the Thermic Effect of Activity (TEA).

$$TEE = BMR + TEF + TEA$$
$$TEA = \text{Planned Exercise Expenditure} + \text{Spontaneous Physical Activity} + \text{Non-Exercise Activity Thermogenesis}$$

Techniques used to measure or estimate components of TEE in sedentary and moderately active populations can also be applied to athletes, but there are some limitations to this approach, particularly in highly competitive athletes. Since the measurement of BMR requires subjects to remain exclusively at rest, it is more practical to measure resting metabolic rate (RMR) which may be 10% higher. Although population-specific regression equations are encouraged, a reasonable estimate of BMR can be obtained using either the Cunningham[4] or the Harris-Benedict[5] equations, with an appropriate activity factor being applied to estimate TEE. Whereas RMR represents 60%–80% of TEE for sedentary individuals, it may be as little as 38%–47% of TEE for elite endurance athletes who may have a TEA as high as 50% of TEE.[2]

TEA includes planned exercise expenditure, spontaneous physical activity (eg, fidgeting), and non-exercise activity thermogenesis. Energy expenditure from exercise (EEE) can be estimated in several ways from activity logs (1–7 days duration) with subjective estimates of exercise intensity using activity codes and metabolic equivalents (METs),[6,7] 2015 US dietary guidelines[8] and the Dietary Reference Intakes (DRIs).[9] The latter two typically underestimate the requirements of athletes since they fail to cover the range in body size or activity levels of competitive populations. Energy availability (EA) is a concept of recent currency in sports nutrition, which equates energy intake with requirements for optimal health and function rather than energy balance. EA, defined as dietary intake minus exercise energy expenditure normalized to FFM, is the amount of energy available to the body to perform all other functions after the cost of exercise is subtracted.[10] The concept was first studied in females, where an EA of 45 kcal/kg FFM/d was found to be associated with energy balance and optimal health; meanwhile, a chronic reduction in EA, (particularly below 30 kcal/kg FFM/d) was associated with impairments of a variety of body functions.[10] Low EA may occur from insufficient EI, high TEE or a combination of the two. It may be associated with disordered eating, a misguided or excessively rapid program for loss of body mass, or inadvertent failure to meet energy requirements during a period of high-volume training or competition.[10]

Example Calculation of Energy Availability (EA):

60 kg body weight (BW), 20% BF, 80% FFM
(=48.0 kg FFM), EI = 2400 kcal/d, EEE = 500 kcal/d

EA = (EI – EEE) / FFM = (2400 – 500) kcal/d / 48.0 kg = 39.6 kcal/kg FFM/d

The concept of EA emerged from the study of Female Athlete Triad (Triad), which started as a recognition of the interrelatedness of clinical issues with disordered eating, menstrual dysfunction, and low bone mineral density in female athletes and then evolved into a broader understanding of the concerns associated with any movement along the spectra away from optimal energy availability, menstrual status, and bone health.[11] Although not embedded in the Triad spectrum, it is recognized that other physiological consequences may result from one of the components of the Triad in female athletes, such as endocrine, gastrointestinal, renal, neuro-psychiatric, musculoskeletal, and cardiovascular dysfunction.[11] Indeed, an extension of the Triad has been proposed, Relative Energy Deficiency in Sport (RED-S), as an inclusive description of the entire cluster of physiological complications observed in male and female athletes who consume energy intakes that are insufficient in meeting the needs for optimal body function once the energy cost of exercise has been removed.[12] Specifically, health consequences of RED-S may negatively affect menstrual function, bone health, endocrine, metabolic, hematological, growth and development, psychological, cardiovascular, gastrointestinal, and immunological systems. Potential performance effects of RED-S may include decreased endurance, increased injury risk, decreased training response, impaired judgment, decreased coordination, decreased concentration, irritability, depression, decreased glycogen stores, and decreased muscle strength.[12] It is now also recognized that impairments of health and function occur across the continuum of reductions in EA, rather than occurring uniformly at an EA threshold, and require further research.[12] It should be appreciated that low EA is not synonymous with negative EB or weight loss; indeed, if a reduction in EA is associated with a reduction in RMR, it may produce a new steady-state of EB or weight stability at a lowered energy intake that is insufficient to provide for healthy body function.

Regardless of the terminology, it is apparent that low EA in male and female athletes may compromise athletic performance in the short and long-term. Screening and treatment guidelines have been established for management of low EA[11,12] and should include assessment with the Eating Disorder Inventory-3 resource[13] or the DSM-5, which includes changes in eating disorder criteria.[14] There is evidence that interventions to increase EA are successful in reversing at least some impaired body functions; for example, in a 6-month trial with female athletes experiencing menstrual dysfunction, dietary treatment to increase EA to ~40 kcal/kg FFM/d resulted in resumption of menses in all subjects in a mean of 2.6 months.[6]

Body Composition and Sports Performance

Various attributes of physique (body size, shape and composition) are considered to contribute to success in various sports. Of these, body mass ("weight") and body composition are often focal points for athletes since they are most able to be manipulated. Although it is clear that the assessment and manipulation of body composition may assist in the progression of an athletic career, athletes, coaches, and trainers should be reminded that athletic performance cannot be accurately predicted solely based on body weight and composition. A single and rigid "optimal" body composition should not be recommended for any event or group of athletes.[15] Nevertheless, there are relationships between body composition and sports performance that are important to consider within an athlete's preparation.

In sports involving strength and power, athletes strive to gain fat-free mass via a program of muscle hypertrophy at specified times of the annual macro-cycle. Whereas some athletes aim to gain absolute size and strength per se, in other sports, in which the athlete must move their own body mass or compete within weight divisions, it is important to optimize power to weight ratios rather than absolute power.[16] Thus, some power athletes also desire to achieve low body fat levels. In sports involving weight divisions (eg. combat sports, lightweight rowing, weightlifting), competitors typically target the lowest achievable body weight category, while maximizing their lean mass within this target.

Other athletes strive to maintain a low body mass and/or body fat level for separate advantages.[17] Distance runners and cyclists benefit from a low energy cost of movement and a favorable ratio of weight to surface area for heat dissipation. Team athletes can increase their speed and agility by being lean, while athletes in acrobatic sports (eg, diving. gymnastics, dance) gain biomechanical advantages in being able to move their bodies within a smaller space. In some of these sports and others (eg, body building), there is an element of aesthetics in determining performance outcomes. Although there are demonstrated advantages to achieving a certain body composition, athletes may feel pressure to strive to achieve unrealistically low targets of weight/body fat or to reach them in an unrealistic time frame.[15] Such athletes may be susceptible to practicing extreme weight control behaviors or continuous dieting, exposing themselves to chronic periods of low EA and poor nutrient support in an effort to repeat previous success at a lower weight or leaner body composition.[15,18] Extreme methods of weight control can be detrimental to health and performance, and disordered eating patterns have also been observed in these sport scenarios.[15,18]

Nevertheless, there are scenarios in which an athlete will enhance their health and performance by reducing body weight or body fat as part of a periodized strategy. Ideally, this occurs within a program that gradually achieves an individualized "optimal" body composition over the athlete's athletic career, and allows weight and body fat to track within a suitable range within the annual training cycle.[18] The program should also include avoiding situations in which athletes inadvertently gain excessive amounts of body fat as a result of a sudden energy mismatch when energy expenditure is abruptly reduced (eg, the off-season or injury). In addition, athletes are warned against the sudden or excessive gain in body fat which is part of the culture of some sports where a high body mass is deemed useful for performance. Although body mass index is not appropriate as a body composition surrogate in athletes, a chronic interest in gaining weight may put some athletes at risk for an "obese" body mass index which may increase the risk of meeting the criteria for metabolic syndrome.[19] Sports dietitians should be aware of sports that promote the attainment of a large body mass and screen for metabolic risk factors.[19]

Methodologies for body composition assessment. Techniques used to assess athlete body composition include dual energy x-ray absorptiometry (DXA), hydrodensitometry, air displacement plethysmography, skinfold measurements, and single and multi-frequency bioelectrical impedance analysis. Although DXA is quick and noninvasive, issues around cost, accessibility, and exposure to a small radiation dose limit its utility, particularly for certain populations.[20] When undertaken according to standardized protocols, DXA has the lowest standard error of estimate while skinfold measures have the highest. Air displacement plethysmography (BodPod, Life Measurement, Inc., Concord, CA) provides an alternative method that is quick and reliable, but may underestimate body fat by 2%–3%.[20] Skinfold measurement and other anthropometric data serve as an excellent surrogate measure of adiposity and muscularity when profiling composition changes in response to training interventions.[20] However, it should be noted that the standardization of skinfold sites, measurement techniques, and calipers vary around the world. Despite some limitations, this technique remains a popular method of choice due to convenience and cost, with information being provided in absolute measures and compared with sequential data from the individual athlete or, in a general way, with normative data collected in the same way from athlete populations.[20,21]

All body composition assessment techniques should be scrutinized to ensure accuracy and reliability. Testing should be conducted with the same calibrated equipment, with a standardized protocol, and by technicians with known test-retest reliability. Where population–specific prediction equations are used, they should be cross-validated and reliable. Athletes should be educated on the limitations associated with body composition assessment and should strictly follow pre-assessment protocols. These instructions which include maintaining a consistent training volume, fasting status, and hydration from test to test[20] should be enforced to avoid compromising the accuracy and reliability of body composition measures.

Body composition should be determined within a sports program according to a schedule that is appropriate to the performance of the event, the practicality of undertaking assessments, and the sensitivity of the athlete. There are technical errors associated with all body composition techniques that limit the usefulness of measurement for athlete selection and performance prediction. In lieu of setting absolute body composition goals or applying absolute criteria to categorize groups of athletes, it is preferred that normative data are provided in terms of ranges.[21] Since body fat content for an individual athlete will vary over the season and over the athlete's career, goals for body composition should be set in terms of ranges that can be appropriately tracked at critical times. When conducting such monitoring programs, it is important that the communication of results with coaches, training staff, and athletes is undertaken with sensitivity, that limitations in measurement technique are recognized, and that care is taken to avoid promoting an unhealthy obsession with body composition.[17,18] Sports dietitians have important opportunities to work with these athletes to help promote a healthy body composition, and to minimize their reliance on rapid-weight loss techniques and other hazardous practices that may result in performance decrements, loss of fat-free mass, and chronic health risks. Many themes should be addressed and include the creation of a culture and environment that values safe and long-term approaches to management of body composition; modification of rules or practices around selection and qualification for weight classes;[16,19,22] and programs that identify disordered eating practices at an early stage for intervention, and where necessary, removal from play.[18]

Principles of altering body composition and weight. Athletes often need assistance in setting appropriate short-term and long-term goals, understanding nutritional practices that can safely and effectively increase muscle mass or reduce body fat/weight, and integrating these strategies into an eating plan that achieves other performance nutrition goals. Frequent follow up with these athletes may have long-term benefits including shepherding the athlete through short-term goals and reducing reliance on extreme techniques and fad diets/behaviors.

There is ample evidence in weight sensitive and weight-making sports that athletes frequently undertake rapid weight loss strategies to gain a competitive advantage.[20,23,24] However, the resultant hypohydration (body water deficit), loss of glycogen stores and lean mass, and other outcomes of pathological behaviors (eg, purging, excessive training, starving) can impair health and performance.[18] Nevertheless, responsible use of short-term, rapid weight loss techniques, when indicated, is preferred over extreme and extended energy restriction and suboptimal nutrition support.[17] When actual loss of body weight is required, it should be programmed to occur in the base phase of training or well out from competition to minimize loss of performance,[25] and should be achieved with techniques that maximize loss of body fat while preserving muscle mass and other health goals. Such strategies include achieving a slight energy deficit to achieve a slow rather than rapid rate of loss and increasing dietary protein intake. In this regard, the provision of a higher protein intake (2.3 vs 1 g/kg/d) in a shorter-term (2 w), energy-restricted diet in athletes was found to retain muscle mass while losing weight and body fat.[26] Furthermore, fat-free mass and performance may be better preserved in athletes who minimize weekly weight loss to <1% per week. [25]

An individualized diet and training prescription for weight/fat loss should be based on assessment of goals, present training and nutrition practices, past experiences, and trial and error. Nevertheless, for most athletes, the practical approach of decreasing energy intake by ~250–500 kcal/d from their periodized energy needs, while either maintaining or slightly increasing energy expenditure, can achieve progress towards short-term body composition goals over approximately 3–6 weeks. In some situations, additional moderate aerobic training and close monitoring can be useful.[27] These strategies can be implemented to help augment the diet-induced energy deficits without negatively impacting recovery from sport-specific training. Arranging the timing and content of meals to support training nutrition goals and recovery may reduce fatigue during frequent training sessions and may help optimize body composition over time.[18] Overall barriers to body composition management include limited access to healthy food options, limited skills or opportunity for food preparation, lack of daily routine, and exposure to catering featuring unlimited portion sizes and energy-dense foods. Such factors, particularly found in association with the travel and communal living experiences in the athlete lifestyle, can promote poor dietary quality that thwarts progress and may lead to the pursuit of quick fixes, acute dieting, and extreme weight loss practices.

EAL Question #1 (Table 1) examined the effect of negative energy balance on sport performance, finding only fair support for an impairment of physical capacity due to a hypoenergetic diet in the currently examined scenarios. However, few studies have investigated the overlay of factors commonly seen in practice, including the interaction of poor dietary quality, low carbohydrate availability, excessive training, and acute dehydration on chronic energy restriction. The challenge of detecting small but important changes in sports performance is noted in all areas of sports nutrition.[28] EAL Question #2 summarizes the literature on optimal timing, energy, and macronutrient characteristics of a program supporting a gain in fat-free mass when in energy deficit (Table 1). Again the literature is limited in quantity and range to allow definitive recommendations to be made, although there is support for the benefits of increased protein intake.

Macronutrient Requirements for Sport

Energy pathways and training adaptations. Guidelines for the timing and amount of intake of macronutrients in the athlete's diet should be underpinned by a fundamental understanding of how training-nutrient interactions affect energy systems, substrate availability and training adaptations. Exercise is fueled by an integrated series of energy systems which include non-oxidative (phosphagen and glycolytic) and aerobic (fat and carbohydrate oxidation) pathways, using substrates that are both endogenous and exogenous in origin. Adenosine triphosphate and phosphocreatine (phosphagen system) provide a rapidly available energy source for muscular contraction, but not at sufficient levels to provide a continuous supply of energy for longer than ~10 seconds. The anaerobic glycolytic pathway rapidly metabolizes glucose and muscle glycogen through the glycolytic cascade and is the primary pathway supporting high-intensity exercise lasting 10–180 seconds. Since neither the phosphagen nor the glycolytic pathway can sustain energy demands to allow muscles to contract at a very high rate for longer lasting events, oxidative pathways provide the primary fuels for events lasting longer than ~2 minutes. The major substrates include muscle and liver glycogen, intramuscular lipid, adipose tissue triglycerides, and amino acids from muscle, blood, liver and the gut. As oxygen becomes more available to the working muscle, the body uses more of the aerobic (oxidative) pathways and less of the anaerobic (phosphagen and glycolytic) pathways. The greater dependence upon aerobic pathways does not occur abruptly, nor is one pathway ever relied on exclusively. The intensity, duration, frequency, type of training, sex, and training level of the individual, as well as prior nutrient intake and substrate availability, determine the relative contribution of energy pathways and when crossover between pathways occurs. For a more complete understanding of fuel systems for exercise, the reader is directed to specific texts.[29]

An athlete's skeletal muscle has a remarkable plasticity to respond quickly to mechanical loading and nutrient availability resulting in condition-specific metabolic and functional adaptations.[30] These adaptations influence performance nutrition recommendations with the overarching goals that energy systems should be trained to provide the most economical support for the fuel demands of an event while other strategies should achieve appropriate substrate availability during the event itself. Adaptations that enhance metabolic flexibility include increases in transport molecules that carry nutrients across membranes or to the site of their utilization within the muscle cell, increases in enzymes that activate or regulate metabolic pathways, enhancement of the ability to tolerate the side-products of metabolism and an increase in the size of muscle fuel stores.[3] While some muscle substrates (eg, body fat) are present in relatively large quantities, others may need to be manipulated according to specific needs (eg, carbohydrate supplementation to replace muscle glycogen stores).

Carbohydrate. Carbohydrate has rightfully received a great deal of attention in sports nutrition due to a number of special features of its role in the performance of, and adaptation to training. First, the size of body carbohydrate stores is relatively limited and can be acutely manipulated on a daily basis by dietary intake or even a single session of exercise.[3] Second, carbohydrate provides a key fuel for the brain and central nervous system and a versatile substrate for muscular work where it can support exercise over a large range of intensities due to its utilization by both anaerobic and oxidative pathways. Even when working at the highest intensities that can be supported by oxidative phosphorylation, carbohydrate offers advantages over fat as a substrate since it provides a greater yield of adenosine triphosphate per volume of oxygen that can be delivered to the mitochondria,[3] thus improving gross exercise efficiency.[31] Third, there is significant evidence that the performance of prolonged sustained or intermittent high-intensity exercise is enhanced by strategies that maintain high carbohydrate availability (ie, match glycogen stores and blood glucose to the fuel demands of exercise), while depletion of these stores is associated with fatigue in the form of reduced work rates, impaired skill and concentration, and increased perception of effort. These findings underpin the various performance nutrition strategies, to be discussed subsequently, that supply carbohydrate before, during, and in the recovery between events to enhance carbohydrate availability.

Finally, recent work has identified that in addition to its role as a muscle substrate, glycogen plays important direct and indirect roles in regulating the muscle's adaptation to training. [32] The amount and localization of glycogen within the muscle cell alters the physical, metabolic, and hormonal environment in which the signaling responses to exercise are exerted. Specifically, starting a bout of endurance exercise with low muscle glycogen content (e.g. by undertaking a second training session in the hours after the prior session has depleted glycogen stores) produces a coordinated upregulation of the transcriptional and post-translational responses to exercise. A number of mechanisms underpin this outcome including increasing the activity of molecules that have a glycogen binding domain, increasing free fatty acid availability, changing osmotic pressure in the muscle cell and increasing catecholamine concentrations.[32] Strategies that restrict exogenous carbohydrate availability (e.g. exercising in a fasted state or without carbohydrate intake during the session) also promote an extended signaling response, albeit less robustly than is the case for exercise with low endogenous carbohydrate stores.[33] These strategies enhance the cellular outcomes of endurance training such as increased maximal mitochondrial enzyme activities and/or mitochondrial content and increased rates of lipid oxidation, with the augmentation of responses likely to be explained by enhanced activation of key cell signaling kinases (eg, AMPK, p38MAPK), transcription factors (eg, p53, PPARδ) and transcriptional co-activators (eg, PGC-1α).[33] Deliberate integration of such training-dietary strategies ("train low") within the periodized training program is becoming a recognized,[34] although potentially misused,[33] part of sports nutrition practice.

Individualized recommendations for daily intakes of carbohydrate should be made in consideration of the athlete's training/competition program and the relative importance of undertaking it with high or low carbohydrate according to the priority of promoting the performance of high quality exercise versus enhancing the training stimulus or adaptation, respectively. Unfortunately, we lack sophisticated information on the specific substrate requirements of many of the training sessions undertaken by athletes; therefore we must rely on guesswork, supported by information on work requirements of exercise from technologies such as consumer-based activity and heart rate monitors,[35] power meters, and global positioning systems.

General guidelines for the suggested intake of carbohydrate to provide high carbohydrate availability for designated training or competition sessions can be provided according to the athlete's body size (a proxy for the size of muscle stores) and the characteristics of the session (Table 2). The timing of carbohydrate intake over the day and in relation to training can also be manipulated to promote or reduce carbohydrate availability.[36] Strategies to enhance carbohydrate availability are covered in more detail in relation to competition eating strategies. Nevertheless, these fueling practices are also important for supporting the high quality workouts within the periodized training program. Furthermore, it is intuitive that they add value in fine-tuning intended event eating strategies, and for promoting adaptations such as gastrointestinal tolerance and enhanced intestinal absorption[37] that allow competition strategies to be fully effective. During other sessions of the training program, it may be less important to achieve high carbohydrate availability, or there may be some value in deliberately exercising with low carbohydrate availability to enhance the training stimulus or adaptive response. Various tactics can be used to permit or promote low carbohydrate availability including reducing total carbohydrate intake or manipulating the timing of training in relation to carbohydrate intake (eg, training in a fasted state, undertaking two bouts of exercise in close proximity without opportunity for refueling between sessions).[38]

Specific questions examined via the evidence analysis on carbohydrate needs for training are summarized in Table 2 and show good evidence that neither the glycemic load nor glycemic index of carbohydrate-rich meals affects the metabolic nor performance outcomes of training once

TABLE 2. Summary of guidelines for carbohydrate intake by athletes.[36]

	Situation	Carbohydrate Targets	Comments on Type and Timing of Carbohydrate Intake
DAILY NEEDS FOR FUEL AND RECOVERY			
1. The following targets are intended to provide high carbohydrate availability (ie, to meet the carbohydrate needs of the muscle and central nervous system) for different exercise loads for scenarios where it is important to exercise with high quality and/or at high intensity. These general recommendations should be fine-tuned with individual consideration of total energy needs, specific training needs and feedback from training performance. 2. On other occasions, when exercise quality or intensity is less important, it may be less important to achieve these carbohydrate targets or to arrange carbohydrate intake over the day to optimise availability for specific sessions. In these cases, carbohydrate intake may be chosen to suit energy goals, food preferences, or food availability. 3. In some scenarios, when the focus is on enhancing the training stimulus or adaptive response, low carbohydrate availability may be deliberately achieved by reducing total carbohydrate intake, or by manipulating carbohydrate intake related to training sessions (eg, training in a fasted state, undertaking a second session of exercise without adequate opportunity for refuelling after the first session).			
Light	• Low intensity or skill-based activities	3–5 g/kg of athlete's body weight/d	• Timing of intake of carbohydrate over the day may be manipulated to promote high carbohydrate availability
Moderate	• Moderate exercise program (eg, ~1 h per day)	5–7 g/kg/d	for a specific session by consuming carbohydrate before or during the session, or in recovery from a previous session.
High	• Endurance program (eg, 1–3 h/d mod-high-intensity exercise)	6–10 g/kg/d	• Otherwise, as long as total fuel needs are provided, the pattern of intake may simply be guided by convenience and individual choice.
Very High	• Extreme commitment (eg, >4–5 h/d mod-high intensity exercise	8–12 g/kg/d	• Athletes should choose nutrient-rich carbohydrate sources to allow overall nutrient needs to be met.
ACUTE FUELLING STRATEGIES – these guidelines promote high carbohydrate availability to promote optimal performance in competition or key training sessions			
General fuelling up	• Preparation for events < 90 min exercise	7–12 g/kg per 24 h as for daily fuel needs	• Athletes may choose carbohydrate-rich sources that are low in fiber/residue and easily consumed to ensure that fuel targets are met, and to meet goals for gut comfort or lighter 'racing weight'.
Carbohydrate loading	• Preparation for events > 90 min of sustained/intermittent exercise	36–48 h of 10–12 g/kg body weight per 24 h	
Speedy refuelling	• <8 h recovery between 2 fuel demanding sessions	1–1.2 g/kg/h for first 4 h then resume daily fuel needs	• There may be benefits in consuming small regular snacks • Carbohydrate rich foods and drink may help to ensure that fuel targets are met.
Pre-event fuelling	• Before exercise > 60 min	1–4 g/kg consumed 1–4 h before exercise	• Timing, amount and type of carbohydrate foods and drinks should be chosen to suit the practical needs of the event and individual preferences/experiences. • Choices high in fat/protein/fiber may need to be avoided to reduce risk of gastrointestinal issues during the event. • Low glycemic index choices may provide a more sustained source of fuel for situations where carbohydrate cannot be consumed during exercise.
During brief exercise	• <45 min	Not needed	
During sustained high intensity exercise	• 45–75 min	Small amounts including mouth rinse	• A range of drinks and sports products can provide easily consumed carbohydrate. • The frequent contact of carbohydrate with the mouth and oral cavity can stimulate parts of the brain and central nervous system to enhance perceptions of well-being and increase self-chosen work outputs.
During endurance exercise including 'stop and start' sports	• 1–2.5 h	30–60 g/h	• Carbohydrate intake provides a source of fuel for the muscle to supplement endogenous stores. • Opportunities to consume foods and drinks vary according to the rules and nature of each sport. • A range of everyday dietary choices and specialised sports products ranging in form from liquid to solid may be useful • The athlete should practice to find a refuelling plan that suits their individual goals including hydration needs and gut comfort.
During ultra-endurance exercise	• >2.5–3 h	Up to 90 g/h	• As above. • Higher intakes of carbohydrate are associated with better performance. • Products providing multiple transportable carbohydrates (Glucose:fructose mixtures) achieve high rates of oxidation of carbohydrate consumed during exercise.

carbohydrate and energy content of the diet have been taken into account (Question #11). Furthermore, although there is sound theory behind the metabolic advantages of exercising with low carbohydrate availability on training adaptations, the benefits to performance outcomes are currently unclear (Table 1, Question #10). This possibly relates to the limitations of the few available studies in which poor periodization of this tactic within the training program has meant that any advantages to training adaptations have been counteracted by the reduction in training intensity and quality associated with low carbohydrate variability. Therefore, a more sophisticated approach is needed to integrate this training/nutrient interaction into the larger training program.[33] Finally, while there is support for consuming multiple carbohydrates to facilitate more rapid absorption, evidence to support the choice of special blends of carbohydrate to support increased carbohydrate oxidation during training sessions is premature (Question #9).

Protein. Dietary protein interacts with exercise, providing both a trigger and a substrate for the synthesis of contractile and metabolic proteins[39,40] as well as enhancing structural changes in non-muscle tissues such as tendons[41] and bones.[42] Adaptations are thought to occur by stimulation of the activity of the protein synthetic machinery in response to a rise in leucine concentrations and the provision of an exogenous source of amino acids for incorporation into new proteins.[43] Studies of the response to resistance training show upregulation of muscle protein synthesis (MPS) for at least 24 hours in response to a single session of exercise, with increased sensitivity to the intake of dietary protein over this period.[44] This contributes to improvements in skeletal muscle protein accretion observed in prospective studies that incorporate multiple protein feedings after exercise and throughout the day. Similar responses occur following aerobic exercise or other exercise types (eg, intermittent sprint activities and concurrent exercise), albeit with potential differences in the type of proteins that are synthesized. Recent recommendations have underscored the importance of well-timed protein intake for all athletes even if muscle hypertrophy is not the primary training goal, and there is now good rationale for recommending daily protein intakes that are well above the RDA[39] to maximize metabolic adaptation to training.[40]

Although classical nitrogen balance work has been useful for determining protein requirements to prevent deficiency in sedentary humans in energy balance,[45] athletes do not meet this profile and achieving nitrogen balance is secondary to an athlete with the primary goal of adaptation to training and performance improvement.[40] The modern view for establishing recommendations for protein intake in athletes extends beyond the DRIs. Focus has clearly shifted to evaluating the benefits of providing enough protein at optimal times to support tissues with rapid turnover and augment metabolic adaptations initiated by training stimulus. Future research will further refine recommendations directed at total daily amounts, timing strategies, quality of protein intake, and provide new recommendations for protein supplements derived from various protein sources.

Protein needs. Current data suggest that dietary protein intake necessary to support metabolic adaptation, repair, remodeling, and for protein turnover generally ranges from 1.2 to 2.0 g/kg/d. Higher intakes may be indicated for short periods during intensified training or when reducing energy intake.[26,39] Daily protein intake goals should be met with a meal plan providing a regular spread of moderate amounts of high-quality protein across the day and following strenuous training sessions. These recommendations encompass most training regimens and allow for flexible adjustments with periodized training and experience.[46,47] Although general daily ranges are provided, individuals should no longer be solely categorized as strength or endurance athletes and provided with static daily protein intake targets. Rather, guidelines should be based around optimal adaptation to specific sessions of training/competition within a periodized program, underpinned by an appreciation of the larger context of athletic goals, nutrient needs, energy considerations, and food choices. Requirements can fluctuate based on "trained" status (experienced athletes requiring less), training (sessions involving higher frequency and intensity, or a new training stimulus at higher end of protein range), carbohydrate availability, and most importantly, energy availability.[46,48] The consumption of adequate energy, particularly from carbohydrates, to match energy expenditure, is important so that amino acids are spared for protein synthesis and not oxidized.[49] In cases of energy restriction or sudden inactivity as occurs as a result of injury, elevated protein intakes as high as 2.0 g/kg/day or higher[26,50] when spread over the day may be advantageous in preventing fat-free mass loss.[39] More detailed reviews of factors that influence changing protein needs and their relationship to changes in protein metabolism and body composition goals can be found elsewhere.[51,52]

Protein timing as a trigger for metabolic adaptation. Laboratory based studies show that MPS is optimized in response to exercise by the consumption of high biological value protein, providing ~10 g essential amino acids in the early recovery phase (0–2 h after exercise).[40,53] This translates to a recommended protein intake of 0.25–0.3 g/kg body weight or 15–25 g protein across the typical range of athlete body sizes, although the guidelines may need to be fine-tuned for athletes at extreme ends of the weight spectrum.[54] Higher doses (ie, >40 g dietary protein) have not yet been shown to further augment MPS and may only be prudent for the largest athletes, or during weight loss.[54] The exercise-enhancement of MPS, determined by the timing and pattern of protein intake, responds to further intake of protein within the 24-hour period after exercise,[55] and may ultimately translate into chronic muscle protein accretion and functional change. While protein timing affects MPS rates, the magnitude of mass and strength changes over time are less clear.[56] However, longitudinal training studies currently suggest that increases in strength and muscle mass are greatest with immediate post-exercise provision of protein.[57]

Whereas traditional protein intake guidelines focused on total protein intake over the day (g/kg), newer recommendations now highlight that the muscle adaptation to training can be maximized by ingesting these targets as 0.3 g/kg body weight after key exercise sessions and every 3–5 hours over multiple meals.[47,54,58] Table 1, Question #8 summarizes the weight of the current literature of consuming protein on protein-specific metabolic responses during recovery.

Optimal protein sources. High-quality dietary proteins are effective for the maintenance, repair, and synthesis of skeletal muscle proteins.[59] Chronic training studies have shown that the consumption of milk-based protein after resistance exercise is effective in increasing muscle strength and favorable changes in body composition.[57,60,61] In addition, there are reports of increased MPS and protein accretion with whole milk, lean meat, and dietary supplements, some of which provide the isolated proteins whey, casein, soy, and egg. To date, dairy proteins seem to be superior to other tested proteins, largely due to leucine content and the digestion and absorptive kinetics of branched-chain amino acids in fluid-based dairy foods.[62] However, further studies are warranted to assess other intact high-quality protein sources (eg, egg, beef, pork, concentrated vegetable protein) and mixed meals on mTOR stimulation and MPS following various modes of exercise. When whole food protein sources are not convenient or available, then portable, third-party tested dietary supplements with high-quality ingredients may serve as a practical alternative to help athletes meet their protein needs. It is important to conduct a thorough assessment of the athlete's specific nutrition goals when considering protein supplements. Recommendations regarding protein supplements should be conservative and primarily directed at optimizing recovery and adaptation to training while continuing to focus on strategies to improve or maintain overall diet quality.

Fat. Fat is a necessary component of a healthy diet, providing energy, essential elements of cell membranes and facilitation of the absorption of fat-soluble vitamins. The *Dietary Guidelines for Americans, 2015–2020*[8] and Eating Well with Canada's Food Guide[63] have made recommendations that the proportion of energy from saturated fats be limited to less than 10% and include sources of essential fatty acids to meet adequate intake (AI) recommendations. Intake of fat by athletes should be in accordance with public health guidelines and should be individualized based on training level and body composition goals.[46]

Fat, in the form of plasma free fatty acids, intramuscular triglycerides and adipose tissue provides a fuel substrate that is both relatively plentiful and increased in availability to the muscle as a result of endurance training. However, exercise-induced adaptations do not appear to maximize oxidation rates since they can be further enhanced by dietary strategies such as fasting, acute pre-exercise intake of fat and chronic exposure to high-fat, low-carbohydrate diets.[3] Although there has been historical[64] and recently revived[65] interest in chronic adaptation to high-fat low carbohydrate diets, the present evidence suggests that enhanced rates of fat oxidation can only match exercise capacity/performance achieved by diets or strategies promoting high carbohydrate availability at moderate intensities,[64] while the performance of exercise at the higher intensities is impaired.[64,66] This appears to occur as a result of a down-regulation of carbohydrate metabolism even when glycogen is available.[67] Further research is warranted both in view of the current discussions[65] and the failure of current studies to include an adequate control diet that includes contemporary periodized dietary approaches.[68] Although specific scenarios may exist where high-fat diets may offer some benefits or at least the absence of disadvantages for performance, in general they appear to reduce rather than enhance metabolic flexibility by reducing carbohydrate availability and capacity to use it effectively as an exercise substrate. Therefore, competitive athletes would be unwise to sacrifice their ability to undertake high-quality training or high-intensity efforts during competition that could determine the outcome.[68]

Conversely, athletes may choose to excessively restrict their fat intake in an effort to lose body weight or improve body composition. Athletes should be discouraged from chronic implementation of fat intakes below 20% of energy intake since the reduction in dietary variety often associated with such restrictions is likely to reduce the intake of a variety of nutrients such as fat-soluble vitamins and essential fatty acids,[9] especially n-3 fatty acids. If such focused restrictiveness around fat intake is practiced, it should be limited to acute scenarios such as the pre-event diet or carbohydrate-loading where considerations of preferred macronutrients or gastrointestinal comfort have priority.

Alcohol. Alcohol consumption may be part of a well-chosen diet and social interactions, but excessive alcohol consistent with binge drinking patterns is a concerning behavior observed among some athletes, particularly in team sports.[69] Misuse of alcohol can interfere with athletic goals in a variety of ways related to the negative effects of acute intake of alcohol on the performance of, or recovery from, exercise, or the chronic effects of binge drinking on health and management of body composition.[70] Besides the calorie load of alcohol (7 kcal/g), alcohol suppresses lipid oxidation, increases unplanned food consumption and may compromise the achievement of body composition goals. Research in this area is fraught with study design concerns that limit direct translation to athletes.

Available evidence warns against intake of significant amounts of alcohol in the pre-exercise period and during training due to the direct negative effects of alcohol on exercise metabolism, thermoregulation, and skills/concentration.[69] The effects of alcohol on strength and performance may persist for several hours even after signs and symptoms of intoxication or hangover are no longer present. In the post-exercise phase, where cultural patterns in sport often promote alcohol use, alcohol may interfere with recovery by impairing glycogen storage, [71] slowing rates of rehydration via its suppressive effect on anti-diuretic hormone,[72] and impairing the MPS desired for adaptation and repair.[69,73,74] In cold environments, alcohol consumption increases peripheral vasodilation resulting in core temperature dysregulation[75] and there are likely to be other effects on body function such as disturbances in acid–base balance and cytokine-prostaglandin pathways, and compromised glucose metabolism and cardiovascular function.[76] Binge drinking may indirectly affect recovery goals due to inattention to guidelines for recovery. Binge drinking is also associated with high-risk behaviors leading to accidents and anti-social behaviors that can be detrimental to the athlete. In conclusion, athletes are advised to consider both public health guidelines and team rules regarding use of alcohol and are encouraged to minimize or avoid alcohol consumption in the post-exercise period when issues of recovery and injury repair are a priority.

Micronutrients. Exercise stresses many of the metabolic pathways in which micronutrients are required, and training may result in muscle biochemical adaptations that increase the need for some micronutrients. Athletes who frequently restrict energy intake, rely on extreme weight-loss practices, eliminate one or more food groups from their diet, or consume poorly chosen diets, may consume sub-optimal amounts of micronutrients and benefit from micronutrient supplementation.[77] This occurs most frequently in the case of calcium, vitamin D, iron, and some antioxidants.[78–80] Single-micronutrient supplements are generally only appropriate for correction of a clinically-defined medical reason [eg, iron supplements for iron deficiency anemia (IDA)].

Micronutrients of key interest: Iron. Iron deficiency, with or without anemia, can impair muscle function and limit work capacity [78,81] leading to compromised training adaptation and athletic performance. Suboptimal iron status often results from limited iron intake from heme food sources and inadequate energy intake (approximately 6 mg iron is consumed per ~1,000 kcals).[82] Periods of rapid growth, training at high altitudes, menstrual blood loss, foot-strike hemolysis, blood donation, or injury can negatively impact iron status.[79,81] Some athletes in intense training may also have increased iron losses in sweat, urine, feces, and from intravascular hemolysis.

Regardless of the etiology, a compromised iron status can negatively impact health, physical and mental performance, and warrants prompt medical intervention and monitoring.[83] Iron requirements for all female athletes may be increased by up to 70% of the estimated average requirement.[84] Athletes who are at greatest risk, such as distance runners, vegetarian athletes, or regular blood donors should be screened regularly and aim for an iron intake greater than their RDA (ie, >18 mg for women and >8 mg for men).[81,85]

Athletes with iron deficiency anemia (IDA) should seek clinical follow up, with therapies including oral iron supplementation,[86] improvements in diet and a possible reduction in activities that impact iron loss (eg, blood donation, a reduction in weight bearing training to lessen erythrocyte hemolysis).[87] The intake of iron supplements in the period immediately after strenuous exercise is contra-indicated since there is the potential for elevated hepcidin levels to interfere with iron absorption.[88] Reversing IDA can require 3 to 6 months; therefore, it is advantageous to begin nutrition intervention before IDA develops.[78,81] Athletes who are concerned about iron status or have iron deficiency without anemia (eg, low ferritin without IDA) should adopt eating strategies that promote an increased intake of food sources of well-absorbed iron (eg, heme iron, non-heme iron + vitamin C foods) as the first line of defense. Although there is some evidence that iron supplements can achieve performance improvements in athletes with iron depletion who are not anemic,[89] athletes should be educated that routine, unmonitored supplementation is not recommended, not considered ergogenic without clinical evidence of iron depletion, and may cause unwanted gastrointestinal distress.[89]

Some athletes may experience a transient decrease in hemoglobin at the initiation of training due to hemodilution, known as "dilutional" or "sports anemia", and may not respond to nutrition intervention. These changes appear to be a beneficial adaptation to aerobic training and do not negatively impact performance.[79] There is no agreement on the serum ferritin level that corresponds to a problematic level of iron depletion/deficiency, with various suggestions ranging from <10 to <35 ng/mL.[86] A thorough clinical evaluation in this scenario is warranted since ferritin is an acute-phase protein that increases with inflammation, but in the absence of inflammation, still serves as the best early indicator of compromised iron status. Other markers of iron status and other issues in iron metabolism (e.g. the role of hepcidin) are currently being explored.[88]

Micronutrients of key interest: Vitamin D. Vitamin D regulates calcium and phosphorus absorption and metabolism, and plays a key role in maintaining bone health. There is also emerging scientific interest in the biomolecular role of vitamin D in skeletal muscle[90] where its role in mediating muscle metabolic function[91] may have implications for supporting athletic performance. A growing number of studies have documented the relationship between vitamin D status and injury prevention,[92] rehabilitation,[93] improved neuromuscular function,[94] increased type II muscle fiber size,[94] reduced inflammation,[93] decreased risk of stress fracture,[92,95] and acute respiratory illness.[95]

Athletes who live at latitudes >35th parallel or who primarily train and compete indoors are likely at higher risk for vitamin D insufficiency (25(OH) D = 50-75 nmol/L) and deficiency (25(OH) D <50 nmol/L). Other factors and lifestyle habits such as dark complexion, high body fat content, undertaking of training in the early morning and evening when UVB levels are low, and aggressive blocking of UVB exposure (clothing, equipment, and screening/blocking lotions) increase the risk for insufficiency and deficiency.[93] Since athletes tend to consume little vitamin D from the diet[93] and dietary interventions alone have not been shown to be a reliable means to resolve insufficient status,[96] supplementation above the current RDA and/or responsible UVB exposure may be required to maintain sufficient vitamin D status. A recent study of NCAA Division 1 swimmers and divers reported that athletes who started at 130 nmol/L and received daily doses of 4,000 IU of vitamin D (100 μg) were able to maintain sufficient status over 6 months (mean change +2.5 nmol/L), while athletes receiving placebo experienced a mean loss of 50 nmol/L.[97] Unfortunately, determining vitamin D requirements for optimal health and performance is a complex process. Vitamin D blood levels from 80 nmol/L and up to 100 nmol/L[93] to 125 nmol/L[94] have been recognized as prudent goals for optimal training induced adaptation. Although proper assessment and correction of deficiency is likely vital to athlete well-being and athletic success, current data do not support vitamin D as an ergogenic aid for athletes. Empirical data are still needed to elucidate the direct role of vitamin D in musculoskeletal health and function to help refine recommendations for athletes. Until then, athletes with a history of stress fracture, bone or joint injury, signs of over training, muscle pain or weakness, and a lifestyle involving low exposure to UVB may require 25(OH)D assessment[98] to determine if an individualized vitamin D supplementation protocol is required.

Micronutrients of key interest: Calcium. Calcium is especially important for growth, maintenance, and repair of bone tissue; regulation of muscle contraction; nerve conduction; and normal blood clotting. The risk of low bone-mineral density and stress fractures is increased by low energy availability, and in the case of female athletes, menstrual dysfunction, with low dietary calcium intake contributing further to the risk.[78,99,100] Low calcium intakes are associated with restricted energy intake, disordered eating and/or the specific avoidance of dairy products or other calcium-rich foods. Calcium supplementation should be determined after a thorough assessment of usual dietary intake. Calcium intakes of 1,500 mg/d and 1,500–2,000 IU/day of vitamin D are needed to optimize bone health in athletes with low energy availability or menstrual dysfunctions.[12]

Micronutrients of key interest: Antioxidants. Antioxidant nutrients play important roles in protecting cell membranes from oxidative damage. Because exercise can increase oxygen consumption by 10- to 15-fold, it has been hypothesized that chronic training contributes a constant "oxidative stress" on cells.[101] Acute exercise is known to increase levels of lipid peroxide by-products,[101] but also results in a net increase in native antioxidant system functions and reduced lipid peroxidation.[102] Thus, a well-trained athlete may have a more developed endogenous antioxidant system than a less-active individual and may not benefit from antioxidant supplementation, especially if consuming a diet high in antioxidant rich foods. There is little evidence that antioxidant supplements enhance athletic performance[101] and the interpretation of existing data is confounded by issues of study design (eg, a large variability in subject characteristics, training protocols, and the doses and combinations of antioxidant supplements; the scarcity of crossover designs). There is also some evidence that antioxidant supplementation may negatively influence training adaptations.[103]

The safest and most effective strategy regarding micronutrient antioxidants is to consume a well-chosen diet containing antioxidant-rich foods. The importance of reactive oxygen species in stimulating optimal adaptation to training merits further investigation, but the current literature does not support antioxidant supplementation as a means to prevent exercise induced oxidative stress. If athletes decide to pursue supplementation, they should be advised not to exceed the Tolerable Upper Intake Levels since higher doses could be pro-oxidative.[101] Athletes at greatest risk for poor antioxidant intakes are those who restrict energy intake, follow a chronic low-fat diet, or limit dietary intake of fruits, vegetables, and whole grains.[46]

In summary of the micronutrients, athletes should be educated that the intake of vitamin and mineral supplements does not improve performance unless reversing a pre-existing deficiency[78,79]and the literature to support micronutrient supplementation is often marred with equivocal findings and weak evidence. Despite this, many athletes unnecessarily consume micronutrient supplements even when dietary intake meets micronutrient needs. Rather than self-diagnosing the need for micronutrient supplementation, when relevant, athletes should seek clinical assessment of their micronutrient status within a larger assessment of their overall dietary practices. Sports dietitians can offer several strategies for assessing micronutrient status based on collection of a nutrient intake history along with observing signs and symptoms associated with micronutrient deficiency. This is particularly important for iron, vitamin D, calcium, and antioxidants. By encouraging athletes to consume a well-chosen diet focused on food variety, sports dietitians can help athletes avoid micronutrient deficiencies and gain the benefits of many other performance-promoting eating strategies. Public health guidelines such as the DRIs provide micronutrient intake recommendations for sports dietitians to help athletes avoid both deficiency and safety concerns associated with excessive intake. Micronutrient intake from dietary sources and fortified foods should be assessed alongside micronutrient intake from all other dietary supplements.

THEME 2: PERFORMANCE NUTRITION: STRATEGIES TO OPTIMIZE PERFORMANCE AND RECOVERY FOR COMPETITION AND KEY TRAINING SESSIONS

Pre-, During and Post-Event Eating

Strategies implemented in pre-, during, and post-exercise periods must address a number of goals. First they should support or promote optimal performance by addressing various factors related to nutrition that can cause fatigue and deterioration in the outputs of performance (eg, power, strength, agility, skill, and concentration) throughout or towards the end of the sporting event. These factors include, but are not limited to, dehydration, electrolyte imbalances, glycogen depletion, hypoglycemia, gastrointestinal discomfort/upset, and disturbances to acid–base balance. Fluids or supplements consumed before, during, or in the recovery between sessions can reduce or delay the onset of these factors. Strategies include increasing or replacing key exercise fuels and providing substrates to return the body to homeostasis or further adapt to the stress incurred during a previous exercise session. In some cases, pre-event nutrition may need to redress the effects of other activities undertaken by the athlete during event preparation such as dehydration or restrictive eating associated with ”making weight” in weight category sports. A secondary goal is to achieve gut comfort throughout the event, avoiding feelings of hunger or discomfort and gastrointestinal upsets that may directly reduce the enjoyment and performance of exercise and interfere with ongoing nutritional support. A final goal is to continue to provide nutritional support for health and further adaptation to exercise, particularly in the case of competitive events that span days and weeks (eg, tournaments and stage races).

Nutrient needs and the practical strategies for meeting them pre, during, and post exercise depend on a variety of factors including the event (mode, intensity, duration of exercise), the environment, carryover effects from previous exercise, appetite, and individual responses and preferences. In competitive situations, rules of the event and access to nutritional support may also govern the opportunities for food intake. It is beyond the scope of this review to provide further discussion other than to comment that solutions to feeding challenges around exercise require experimentation and habituation by the athlete, and are often an area in which the food knowledge, creativity, and practical experiences of the sports dietitian make valuable contributions to the athlete’s nutrition plan. Such scenarios are also where the use of sports foods and supplements are often most valuable, since well-formulated products can often provide a practical form of nutritional support to meet specialized nutrient needs.

Hydration Guidelines: Fluid and Electrolyte Balance

Being appropriately hydrated contributes to optimal health and exercise performance. In addition to the usual daily water losses from respiration, gastrointestinal, renal, and sweat sources, athletes need to replace sweat losses. Sweating assists with the dissipation of heat, generated as a byproduct of muscular work but is often exacerbated by environmental conditions, and thus helps maintain body temperature within acceptable ranges.[104] Dehydration refers to the process of losing body water and leads to hypohydration. Although it is common to interchange these terms, there are subtle differences since they reflect process and outcome.

Through a cascade of events, the metabolic heat generated by muscle contractions during exercise can eventually lead to hypovolemia (decreased plasma/blood volume) and thus, cardiovascular strain, increased glycogen utilization, altered metabolic and CNS function, and a greater rise in body temperature.[104–106] Although it is possible to be hypohydrated but not hyperthermic (defined as core body temperature exceeding 40°C; 104°F),[107] in some scenarios the extra thermal strain associated with hypohydration can contribute to an increased risk of life-threatening exertional heat illness (heatstroke). In addition to water, sweat contains substantial but variable amounts of sodium, with lesser amounts of potassium, calcium, and magnesium.[104] To preserve homeostasis, optimal body function, performance, and perception of well-being, athletes should strive to undertake strategies of fluid management before, during, and after exercise that maintain euhydration. Depending on the athlete, the type of exercise, and the environment, there are situations when this goal is more or less important.

Although there is complexity and individuality in the response to dehydration, fluid deficits of >2% body weight can compromise cognitive function and aerobic exercise performances, particularly in hot weather.[104,105,108,109] Decrements in the performance of anaerobic or high-intensity activities, sport-specific technical skills, and aerobic exercise in a cool environment are more commonly seen when 3%–5% of BW is lost due to dehydration.[104,105] Severe hypohydration with water deficits of 6%–10% BW has more pronounced effects on exercise tolerance, decreases in cardiac output, sweat production, skin and muscle blood flow.[107]

Assuming an athlete is in energy balance, daily hydration status may be estimated by tracking early morning body weight (measured upon waking and after voiding) since acute changes in body weight generally reflect shifts in body water. Urinary specific gravity and urine osmolality can also be used to approximate hydration status by measuring the concentration of the solutes in urine. When assessed from a midstream collection of the first morning urine sample, a urinary specific gravity of < 1.020, perhaps ranging to < 1.025 to account for individual variability,[106] is generally indicative of euhydration. Urinary osmolality reflects hypohydration when >900 mOsmol/kg, while euhydration is considered as <700 mOsmol/kg.[104,106]

Before exercise. Some athletes begin exercise in a hypohydrated state, which may adversely affect athletic performances.[105,110] Purposeful dehydration to “make weight” may result in a significant fluid deficit, which may be difficult to restore between “weigh-in” and start of competition. Similarly, athletes may be hypohydrated at the onset of exercise due to recent, prolonged training sessions in the heat or to multiple events in a day.[104,105,108,110]

Athletes may achieve euhydration prior to exercise by consuming a fluid volume equivalent to 5–10 ml/kg BW (~2–4 ml/lb) in the 2 to 4 hours before exercise to achieve urine that is pale yellow in color while allowing for sufficient time for excess fluid to be voided.[104,108] Sodium consumed in pre-exercise fluids and foods may help with fluid retention. Although some athletes attempt to hyper-hydrate prior to exercise in hot conditions where the rates of sweat loss or restrictions on fluid intake inevitably lead to a significant fluid deficit, the use of glycerol and other plasma expanders for this purpose is now prohibited by the World Anti-Doping Agency (www.wada-ama.org).

During exercise. Sweat rates vary during exercise from 0.3–2.4 L/h dependent on exercise intensity, duration, fitness, heat acclimatization, altitude, and other environmental conditions (heat, humidity, etc.).[104,106,111,112] Ideally, athletes should drink sufficient fluids during exercise to replace sweat losses such that the total body fluid deficit is limited to <2% BW. Various factors may impair the availability of fluid or opportunities to consume it during exercise and for most competitive, high caliber athletes, sweat loss generally exceeds fluid intake. However, individual differences are seen in drinking behavior and sweat rates in sport, and result in a range of changes in fluid status from substantial dehydration to over-hydration.[110]

Routine measurement of pre- and post-exercise BW, accounting for urinary losses and drink volume, can help the athlete estimate sweat losses during sporting activities to customize their fluid replacement strategies.[104] In the absence of other factors that alter body mass during exercise (eg, the significant loss of substrate which may occur during very prolonged events), a loss of 1 kg BW represents approximately 1 L sweat loss. The fluid plan that suits most athletes and athletic events will typically achieve an intake of 0.4 to 0.8 L/h,[104] although this needs to be customized to the athlete's tolerance and experience, their opportunities for drinking fluids and the benefits of consuming other nutrients (eg, carbohydrate) in drink form. Ingestion of cold beverages (0.5 °C) may help reduce core temperature and thus improve performance in the heat. The presence of flavor in a beverage may increase palatability and voluntary fluid intake.

Although the typical outcome for competitive athletes is to develop a fluid deficit over the course of an exercise session, over the past 2 decades there has been an increasing awareness that some recreational athletes drink at rates that exceed their sweat losses and over-hydrate. Over-drinking fluids in excess of sweat and urinary losses is the primary cause of hyponatremia (blood sodium <135 mmol/L), also known as water intoxication, although this can be exacerbated in cases where there are excessive losses of sodium in sweat and fluid replacement involving low-sodium beverages.[113,114] It can also be compounded by excessive fluid intake in the hours or days leading up to the event. Over-hydration is typically seen in recreational athletes since their work outputs and sweat rates are lower than competitive athletes, while their opportunities and belief in the need to drink may be greater. Women generally have a smaller body size and lower sweat rates than males and appear to be at greater risk of over-drinking and possible hyponatremia.[104] Symptoms of hyponatremia during exercise occur particularly when plasma sodium levels fall below 130 mmol/L and include bloating, puffiness, weight gain, nausea, vomiting, headache, confusion, delirium, seizures, respiratory distress, loss of consciousness, and possibly death if untreated. While the prevalence of hypohydration and hypernatremia is thought to be greater than reports of hyperhydration and hyponatremia, the latter are more dangerous and require prompt medical attention.[104,106,114]

Sodium should be ingested during exercise when large sweat sodium losses occur. Scenarios include athletes with high sweat rates (>1.2 L/h), "salty sweat," or prolonged exercise exceeding 2 hours in duration.[105,106,109]Although highly variable, the average concentration of sodium in sweat approximates 50 mmol/L (~1 g/L) and is hypotonic in comparison to blood sodium content. Thirst sensation is often dictated by changes in plasma osmolality and is usually a good indication of the need to drink but not that the athlete is dehydrated.[108] Older athletes may present with age-related decreases in thirst sensation and may need encouragement to drink during and post-exercise.[104]

Although skeletal muscle cramps are typically caused by muscle fatigue, they can occur with athletes from all types of sports in a range of environmental conditions[104] and may be associated with hypohydration and electrolyte imbalances. Athletes who sweat profusely, especially when overlaid with a high sweat sodium concentration, may be at greater risk for cramping, particularly when not acclimatized to the heat and environment.[115]

After exercise. Most athletes finish exercising with a fluid deficit and may need to restore euhydration during the recovery period.[104,110] Rehydration strategies should primarily involve the consumption of water and sodium at a modest rate that minimizes diuresis/urinary losses.[105] The presence of dietary sodium/sodium chloride (from foods or fluids) helps to retain ingested fluids, especially extracellular fluids, including plasma volume. Therefore, athletes should not be advised to restrict sodium in their post-exercise nutrition particularly when large sodium losses have been incurred. Since sweat losses and obligatory urine losses continue during the post-exercise phase, effective rehydration requires the intake of a greater volume of fluid (eg, 125%–150%) than the final fluid deficit (eg, 1.25–1.5 L fluid for every 1 kg BW lost).[104,106] Excessive intake of alcohol in the recovery period is discouraged due to its diuretic effects. However, the previous warnings about caffeine as a diuretic appear to be overstated when it is habitually consumed in moderate (e.g. < 180 mg) amounts.[104]

Carbohydrate Intake Guidelines

Because of its role as an important fuel for the muscle and central nervous system, the availability of carbohydrate stores is limiting for the performance of prolonged continuous or intermittent exercise, and is permissive for the performance of sustained high-intensity sport. The depletion of muscle glycogen is associated with fatigue and a reduction in the intensity of sustained exercise, while inadequate carbohydrate for the central nervous system impairs performance-influencing factors such as pacing, perceptions of fatigue, motor skill, and concentration.[3,116] As such, a key strategy in promoting optimal performance in competitive events or key workouts is matching of body carbohydrate stores with the fuel demands of the session. Strategies to promote carbohydrate availability should be undertaken before, during, or in the recovery between events or high-quality training sessions.

Achieving adequate muscle glycogen stores. Manipulating nutrition and exercise in the hours and days prior to an important exercise bout allows an athlete to commence the session with glycogen stores that are commensurate with the estimated fuel costs of the event. In the absence of severe muscle damage, glycogen stores can be normalised with 24 h of reduced training and adequate fuel intake [117] (Table 2). Events >90 minutes in duration may benefit from higher glycogen stores,[118] which can be achieved by a technique known as carbohydrate loading. This protocol of achieving supercompensation of muscle glycogen evolved from the original studies of glycogen storage in the 1960s and, at least in the case of trained athletes, can be achieved by extending the period of a carbohydrate-rich diet and tapering training over 48 h[36] (Table 2).

Carbohydrate consumed in meals and/or snacks during the 1–4 hours pre-exercise may continue to increase body glycogen stores, particularly liver glycogen levels that have been depleted by the overnight fast.[117] It may also provide a source of gut glucose release during exercise.[117] Carbohydrate intakes of 1–4 g/kg, with timing, amount, and food choices suited to the individual, have been shown to enhance endurance or performance of prolonged exercise (Table 2).[117,119] Generally, foods with a low-fat, low-fiber, and low–moderate protein content are the preferred choice for this pre-event menu since they are less prone to cause gastrointestinal problems and promote gastric emptying.[120] Liquid meal supplements are useful for athletes who suffer from pre-event nerves or an uncertain pre-event timetable and thus prefer a more quickly digested option. Above all, the individual athlete should choose a strategy that suits their situation and their past experiences and can be fine-tuned with further experimentation.

The intake of carbohydrate prior to exercise is not always straightforward since the metabolic effects of the resulting insulin response include a reduction in fat mobilization and utilization and concomitant increase in carbohydrate utilization.[119] In some individuals, this can cause premature fatigue.[121] Strategies to circumvent this problem include ensuring at least 1 g/kg carbohydrate in the pre-event meal to compensate for the increased carbohydrate oxidation, including a protein source at the meal, including some high-intensity efforts in the pre-exercise warm up to stimulate hepatic gluconeogenesis, and consuming carbohydrate during the exercise.[122] Another approach has been suggested in the form of choosing pre-exercise meals from carbohydrate-rich foods with a low glycemic index, which might reduce the metabolic changes associated with carbohydrate ingestion as well as providing a more sustained carbohydrate release during exercise. Although occasional studies have shown that such a strategy enhances subsequent exercise capacity,[123] as summarized by the EAL (Table 1 Question #11) and others,[119] pre-exercise intake of low glycemic index carbohydrate choices has not been found to provide a universal benefit to performance even when the metabolic perturbations of pre-exercise carbohydrate intake are attenuated. Furthermore, consumption of carbohydrate during exercise, as further advised in Table 2, dampens any effects of pre-exercise carbohydrate intake on metabolism and performance.[124]

Depending on characteristics including the type of exercise, the environment, and the athlete's preparation and carbohydrate tolerance, the intake of carbohydrate during exercise provides a number of benefits to exercise capacity and performance via mechanisms including glycogen sparing, provision of an exogenous muscle substrate, prevention of hypoglycemia, and activation of reward centers in the central nervous system.[116] Robust literature on exercise carbohydrate feeding has led to the recognition that different amounts, timing and types of carbohydrate are needed to achieve these different effects, and that the different effects may overlap in various events.[36,125] Table 2 summarizes the current guidelines for exercise fueling, noting opportunities where it may play a metabolic role (events of >60–90 min) and the newer concept of "mouth sensing" where frequent exposure of the mouth and oral cavity to carbohydrate is likely to be effective in enhancing workout and pacing strategies via a CNS effect.[126] Of course, the practical achievement of these guidelines needs to fit the personal preferences and experiences of the individual athlete, and the practical opportunities provided in an event or workout to obtain and consume carbohydrate-containing fluids or foods. A range of everyday foods and fluids and formulated sports products that include sports beverages may be chosen to meet these guidelines; this includes newer products containing mixtures of glucose and fructose (the so-called "multiple transportable carbohydrates"), which aim to increase total intestinal absorption of carbohydrates.[127] Although this could be of use to situations of prolonged exercise where higher rates of exogenous carbohydrate oxidation might sustain work intensity in the face of dwindling muscle glycogen stores, the EAL found that evidence for benefits is currently equivocal (Table 1, Question #9).

Glycogen restoration is one of the goals of post-exercise recovery, particularly between bouts of carbohydrate-dependent exercise where there is a priority on performance in the second session. Refueling requires adequate carbohydrate intake (Table 2) and time. Since the rate of glycogen resynthesis is only ~ 5% per hour, early intake of carbohydrate in the recovery period (~1–1.2 g/kg/h during the first 4–6 hours) is useful in maximizing the effective refueling time.[117] As long as total intake of carbohydrate and energy is adequate and overall nutritional goals are met, meals and snacks can be chosen from a variety of foods and fluids according to personal preferences of type and timing of intake.[36,117] More research is needed to investigate how glycogen storage might be enhanced when energy and carbohydrate intakes are sub-optimal.

Protein intake guidelines. Protein consumption in the immediate pre- and post-exercise period is often intertwined with carbohydrate consumption as most athletes consume foods, beverages, and supplements that contain both macronutrients. Dietary protein consumed in scenarios of low-carbohydrate availability[128] and/or restricted energy intake[53] in the early post-exercise recovery period has been found to enhance and accelerate glycogen repletion. For example, it has been established that recovery of performance[129] and glycogen repletion rates[53] were similar in athletes consuming 0.8 g carbohydrate/kg/BW + 0.4 g protein/kg/BW compared to athletes consuming only carbohydrate (1.2 g/kg/BW). This may support exercise performance and benefit athletes frequently involved in multiple training or competitive sessions over same or successive days.

Although protein intake may support glycogen resynthesis and, when consumed in close proximity to strength and endurance exercise, enhances MPS,[59,130] there is a lack of evidence from well-controlled studies that protein supplementation directly improves athletic performance.[131,132] However, a modest number of studies have reported that ingesting ~50–100 g of protein during the recovery period leads to accelerated recovery of static force and dynamic power production during delayed onset muscle soreness.[133,134] Despite these findings other studies show no performance effects from acute ingestion of protein at intake levels that are much more practical to consume on a regular basis. Furthermore, studies that imply positive findings when the control group receives a flavored water placebo[133] or a placebo that is not isocaloric are unable to rule out the impact of post-exercise energy provision on the observed effect.[134]

Protein ingestion during exercise and during the pre-exercise period seems to have less of an impact on MPS than the post-exercise provision of protein but may still enhance muscle reconditioning depending on the type of training that takes place. Co-ingestion of protein and carbohydrate during 2 hours of intermittent resistance-type exercise has been shown to stimulate MPS during the exercise period[135] and may extend the metabolic adaption window particularly during ultra–endurance-type exercise bouts.[136] Potential benefits of consuming protein before and during exercise may be targeted to athletes focused on the MPS response to resistance exercise and those looking to enhanced recovery from ultra-endurance exercise.

Table 1, EAL Questions 5–7 summarizes the literature on consuming protein alone or in combination with carbohydrate during recovery on several outcomes. More work is needed to elucidate the relevance and practicality of protein consumption on subsequent exercise performance and if mechanisms in this context are exclusive to accelerating muscle glycogen synthesis. The utility of a protein supplement should also be measured against the benefits of consuming protein or amino acids from meals and snacks that are already part of a sports nutrition plan to meet other performance goals.

Dietary supplements and ergogenic aids. External and internal motives to enhance performance often encourage athletes to consider the enticing marketing and testimonials surrounding supplements and sports foods. Sports supplements represent an ever growing industry, but a lack of regulation of manufacture and marketing means that athletes can fall victim to false advertising and unsubstantiated claims.[137] The prevalence of supplementation among athletes has been estimated internationally at 37%–89%, with greater frequencies being reported among elite and older athletes. Motivations for use include enhancement of performance or recovery, improvement or maintenance of health, an increase in energy, compensation for poor nutrition, immune support, and manipulation of body composition,[138,139] yet few athletes undertake professional assessment of their baseline nutritional habits. Furthermore, athletes' supplementation practices are often guided by family, friends, teammates, coaches, the internet, and retailers, rather than sports dietitians and other sport science professionals.[138]

Considerations regarding the use of sports foods and supplements include an assessment of efficacy and potency. In addition, there are safety concerns due to the presence of overt and hidden ingredients that are toxic and the poor practices of athletes in consuming inappropriately large doses or problematic combinations of products. The issue of compliance to anti-doping codes remains a concern with potential contamination with banned or non-permissible substances. This carries significant implications for athletes who compete under anti-doping codes (eg, National Collegiate Athletic Association, World Anti-Doping Agency).[139] A supplement manufacturer's claim of "100% pure," "pharmaceutical grade," "free of banned substances," "Natural Health Product – NHPN/NPN" (in Canada) or possessing a drug identification number are not reliable indications that guarantee a supplement is free of banned substances. However, commercial, third-party auditing programs can independently screen dietary supplements for banned and restricted substances in testing facilities (ISO 17025 accreditation standard)[140] thereby providing a greater assurance of supplement purity for athletes concerned about avoiding doping violations and eligibility.

The ethical use of sports supplements is a personal choice and remains controversial. It is the role of qualified health professionals, such as a sports dietitian, to build rapport with athletes and provide credible, evidence-based information regarding the appropriateness, efficacy and dosage for the use of sports foods and supplements. After completing a thorough assessment of an athlete's nutritional practices and dietary intake, sports dietitians should assist the athlete to determine a cost to benefit analysis of their use of a product, noting that the athlete is responsible for products ingested and any subsequent consequences (ie, legal, health, safety issues).[139]

The benefits of the use of supplements and sports foods include practical assistance to meet sports nutritional goals, prevention or treatment of nutrient deficiencies, a placebo effect, and in some cases, a direct ergogenic effect. However, this must be carefully balanced against risks, and the expense and potential for ergolytic effects.[139,141] Factors to consider in the analysis include a theoretical analysis of the nutritional goal or performance benefit that the product is to address within the athlete's specific training or competition program, the quality of the evidence that the product can address these goals, previous experience regarding individual responsiveness, and the health and legal consequences.

Relatively few supplements that claim ergogenic benefits are supported by sound evidence.[139,141] Research methodologies on the efficacy of sports supplements are often limited by small sample sizes, enrollment of untrained subjects, poor representation of athlete sub-populations (females, older athletes, athletes with disabilities, etc.), performance tests that are unreliable or irrelevant, poor control of confounding variables, and failure to include recommended sports nutrition practices or the interaction with other supplements.[139,141] Even when there is a robust literature on a sports supplement, it may not cover all applications that are specific to an event, environment, or individual athlete. Supplement use is best undertaken as an adjunct to a well-chosen nutrition plan. It is rarely effective outside these conditions and not justified in the case of young athletes who can make significant performance gains via maturation in age, sports experience, and the development of a sports nutrition plan.

It is beyond the scope of this paper to address the multitude of sports supplements used by athletes and caveats surrounding sport-specific rules allowing their use. The Australian Institute of Sport has developed a classification system that ranks sports foods and supplement ingredients based on significance of scientific evidence and whether a product is safe, legal, and effective in improving sports performance.[142] Table 3 serves as a general guide to describe the ergogenic and physiological effects of potentially beneficial supplements and sport foods.[141,143–148] This guide is not meant to advocate specific supplement use by athletes and should only be considered in well-defined situations.

THEME 3: SPECIAL POPULATIONS AND ENVIRONMENTS

Vegetarian Athlete

Athletes may opt for a vegetarian diet for various reasons from ethnic, religious, and philosophical beliefs to health, food aversions, and financial constraints or to disguise disordered eating. As with any self-induced dietary restriction, it would be prudent to explore whether the vegetarian athlete also presents with disordered eating or a frank eating disorder.[13,14] A vegetarian diet can be nutritionally adequate containing high intakes of fruits, vegetables, whole grains, nuts, soy products, fiber, phytochemicals, and antioxidants.[149] Currently, research is lacking regarding the impact on athletic performance from long-term vegetarianism among athletic populations.[150]

Depending on the extent of dietary limitations, nutrient concerns for vegetarianism may include energy, protein, fat, iron, zinc, vitamin B-12,, calcium, n-3 fatty acids,[149] and low intakes of creatine and carnosine.[151] Vegetarian athletes may have an increased risk of lower bone mineral density and stress fractures.[152] Additional practical challenges include gaining access to suitable foods during travel, restaurant dining, and at training camps and competition venues. Vegetarian athletes may benefit from comprehensive dietary assessments and education to ensure their diets are nutritionally sound to support training and competition demands.

Altitude

Altitude exposure (ie, daily or intermittent exposure to >2,000 m, > 6,600 ft) may be a specialized strategy within an athlete's training program or simply their daily training environment.[153] One of the goals of specialized altitude training blocks is to naturally increase red blood cell mass (erythropoiesis) so that greater amounts of oxygen can be carried in the blood to enhance subsequent athletic performances.[112] Initial exposure to altitude leads to a decrease in plasma volume with corresponding increases in hemoglobin concentration. Over time there is a net increase in red cell mass and blood volume therefore greater oxygen carrying capacity.[154] However, possessing sufficient iron stores prior to altitude training is essential to enable hematological adaptations.[154] Consumption of iron-rich foods with or without iron supplementation may be required by athletes before and during altitude exposure.

Specific or chronic exposure to a high altitude environment may increase the risk of illness, infection, and sub-optimal adaptation to exercise due to direct effects of hypobaric hypoxic conditions, an unaccustomed volume and intensity of training, interrupted sleep, and increased UV light exposure.[155] The effects are greater with higher elevation and require more acclimatization to minimize the risk of specific altitude illness. Adequate nutrition is essential to maximize the desired effect from altitude training or to support more chronic exposure to a high altitude environment. Key nutritional concerns include the adequacy of intake of energy, carbohydrate, protein, fluids, iron, and antioxidant-rich foods.[112] An increased risk of dehydration at altitude is associated with initial diuresis, increased ventilation, and low humidity, and exercise sweat losses. Some experts suggest daily fluid needs as high as 4–5 L with altitude training and competition, while others encourage individual monitoring of hydration status to determine fluid requirements at altitude.[112]

Extreme Environments

Extreme environmental challenges (heat, cold, humidity, altitude) require physiological, behavioral, and technological adaptations to ensure athletes are capable of performing at their best. Changes in environmental conditions stimulate thermoregulatory neuronal activity in the brain to increase heat loss (sweating and skin vasodilation), prevent heat loss (skin vasoconstriction), or induce heat gain (shivering). Sympathetic neural activation triggers changes in skin blood flow to vary convective heat transfer from the core to the skin (or vice versa) as required for maintaining an optimal core temperature. Unique considerations of nutrition-related concerns are presented when exercising in hot or cold environments.[107,155,156]

TABLE 3. Dietary supplements and sports foods with evidence-based uses in sports nutrition.

Category	Examples	Use	Concerns	Evidence
Sports food	Sports drinks Sports bars Sports confectionery Sports gels Electrolyte supplements Protein supplements Liquid meal supplements	Practical choice to meet sports nutritional goals especially when access to food, opportunities to consume nutrients or gastrointestinal concerns make it difficult to consume traditional food and beverages	Cost is greater than whole foods May be used unnecessarily or in inappropriate protocols	Burke (2015)[141]
Medical supplements	Iron supplements Calcium supplements Vitamin D supplements Multi-vitamin/mineral n-3 fatty acids	Prevention or treatment of nutrient deficiency under the supervision of appropriate medical/nutritional expert	May be self-prescribed unnecessarily without appropriate supervision or monitoring	Burke (2015)[141]
Specific performance supplements	**Ergogenic effects**	**Physiological effects/mechanism of ergogenic effect**	**Concerns regarding use[a]**	**Evidence**
Creatine	Improves performance of repeated bouts of high-intensity exercise with short recovery periods - Direct effect on competition performance - Enhanced capacity for training	Increases Creatine and Phosphocreatine concentrations May also have other effects such as enhancement of glycogen storage and direct effect on muscle protein synthesis	Associated with acute weight gain (0.6–1 kg) which may be problematic in weight sensitive sports May cause gastrointestinal discomfort Some products may not contain appropriate amounts or forms of creatine	Tarnopolsky (2010)[143]
Caffeine	Reduces perception of fatigue Allows exercise to be sustained at optimal intensity/output for longer	Adenosine antagonist with effects on many body targets including central nervous system Promotes Ca^{2+} release from sarcoplasmic reticulum	Causes side-effects (tremor, anxiety, increased heart rate, etc.) when consumed in high doses Toxic when consumed in very large doses	Astorino (2010)[144] Tarnopolsky (2010)[143]
			Rules of National Collegiate Athletic Association competition prohibit the intake of large doses that produce urinary caffeine levels exceeding 15 ug/ml Some products do not disclose caffeine dose or may contain other stimulants	Burke (2013)[145]
Sodium bicarbonate	Improves performance of events that would otherwise be limited by acid–base disturbances associated with high rates of anaerobic glycolysis - High intensity events of 1–7 minutes - Repeated high-intensity sprints - Capacity for high-intensity 'sprint' during endurance exercise	When taken as an acute dose pre-exercise, increases extracellular buffering capacity	May cause gastrointestinal side-effects which cause performance impairment rather than benefit	Carr (2011)[146]
Beta-alanine	Improves performance of events that would otherwise be limited by acid–base disturbances associated with high rates of anaerobic glycolysis - Mostly targeted at high-intensity exercise lasting 60–240 seconds - May enhance training capacity	When taken in a chronic protocol, achieves increase in muscle carnosine (intracellular buffer)	Some products with rapid absorption may cause paresthesia (tingling sensation)	Quesnele (2014)[147]
Nitrate	Improves exercise tolerance and economy Improves performance in endurance exercise at least in non-elite athletes	Increases plasma nitrite concentrations to increase production of nitric oxide with various vascular and metabolic effects that reduces O_2 cost of exercise	Consumption in concentrated food sources (eg, beetroot juice) may cause gut discomfort and discoloration of urine Efficacy seems less clear cut in high caliber athletes	Jones (2014)[148]

These supplements may perform as claimed but does not imply endorsement by this position stand. [a] Athletes should be assisted to undertake a cost to benefit analysis (141) before using any sports food and supplements with consideration of potential nutritional, physiological, and psychological benefits for their specific event weighed against potential disadvantages. Specific protocols of use should be tailored to the individual scenario (see references for further information) and specific products should be chosen with consideration of the risk of contamination with unsafe or illegal chemicals.

Hot environments. When ambient temperature exceeds body temperature, heat cannot be dissipated by radiation; furthermore, the potential to dissipate heat by evaporation of sweat is substantially reduced when the relative humidity is high.[107,156] Heat illness from extreme heat exposure can result in appetite changes and serious health implications (ie, heat exhaustion and exertional heat stroke). Heat exhaustion is characterized by the inability to sustain cardiac output related to exercise-heat stress causing elevated skin temperatures with or without hyperthermia (>38.5°C). Symptoms of heat exhaustion can include anxiety, dizziness, fainting. Exertional heat stroke (body core hyperthermia, typically >40°C) is the most serious and leads to multi-organ dysfunction, including brain swelling, with symptoms of central nervous system abnormalities, delirium, and convulsions, thus can be life-threatening.[107,156]

Athletes competing in lengthy events conducted in hot conditions (eg, tennis match or marathon) and those forced to wear excessive clothing (eg, American football players or BMX competitors) are at greatest risk of heat illness.[111] Strategies to reduce high skin temperatures and large sweat (fluid and electrolyte) losses are required to minimize cardiovascular and hyperthermic challenges that may impair athletic performance when exercising in the heat; athletes should be regularly monitored when at risk for heat-related illness.[107,156] Specific strategies should include: acclimatization, individualized hydration plans, regular monitoring of hydration status, beginning exercise euhydrated, consuming cold fluids during exercise, and possibly the inclusion of electrolyte sources.[107,156]

Cold environments. Athletic performance in cold environments may present several dietary challenges that require careful planning for optimal nutritional support. A large number of sports train and compete in the cold ranging from endurance athletes (eg, Nordic skiers) through to judged events (eg, free style ski). Furthermore, drastic, unexpected environmental changes can turn a warm-weather event (eg, cross country mountain bike race or triathlon) into extreme cold conditions in a short period of time leaving unprepared athletes confronted with performing in the cold.

Primary concerns of exercising in a cold environment are maintenance of euhydration and body temperature.[156] However, exercise-induced heat production and appropriate clothing are generally sufficient to minimize heat loss.[155,156] When adequately prepared (eg, removing wet clothing, keeping muscles warm after exercise warm-up) athletes can tolerate severe cold in pursuit of athletic success. Smaller, leaner athletes are at greater risk of hypothermia due to increased heat production required to maintain core temperature and decreased insulation from lower body fat. Metabolically, energy requirements (from carbohydrates) are increased, especially when shivering, to maintain core temperature.[155,156]

Several factors can increase the risk of hypohydration when exercising in the cold, such as: cold-induced diuresis, impaired thirst sensation, reduced desire to drink, limited access to fluids, self-restricted fluid intake to minimize urination, sweat losses from over-dressing and increased respiration with high altitude exposure.

In the cold, hypohydration of 2%–3% BW loss is less detrimental to endurance performances than similar losses occurring in the heat.[104,155,156] Severe cold exposure may be problematic on training versus competition days since training duration may exceed competition duration and officials may delay competitions in inclement weather yet athletes may continue to train in similar conditions. Athletes' energy, macronutrient, and fluid intakes should be regularly assessed and changes in body weight and hydration status when exercising in both hot and cold environments. Educating athletes about modifying their energy, carbohydrate intakes, and recovery strategies according to training and competition demands promotes optimal training adaptation and maintenance of health. Practical advice for preparation and selection of appropriate foods and fluids that withstand cold exposure will ensure athletes are equipped to cope with weather extremes.

THEME 4: ROLES AND RESPONSIBILITIES OF THE SPORTS DIETITIAN

Sport nutrition practice requires combined knowledge in several topics: clinical nutrition, nutrition science, exercise physiology, and application of evidence-based research. Increasingly, athletes and active individuals seek professionals to guide them in making optimal food and fluid choices to support and enhance their physical performances. An experienced sports dietitian demonstrates the knowledge, skills, and expertise necessary to help athletes and teams work towards their performance-related goals.

The Commission on Dietetic Registration (the credentialing agency for the Academy of Nutrition and Dietetics) has created a unique credential for registered dietitian nutritionists who specialize in sports dietetic practice with extensive experience working with athletes. The Board Certified Specialist in Sports Dietetics (CSSD) credential is designed as the premier professional sports nutrition credential in the United States and is available internationally, including Canada. Specialists in sports dietetics provide safe, effective, evidence-based nutrition assessments, guidance, and counseling for health and performance for athletes, sport organizations, and physically active individuals and groups. For CSSD certification details refer to the Commission on Dietetic registration: www.cdrnet.org. Enhancement of sport nutrition knowledge and continuing education can also be achieved by completing recognized post-graduate qualifications such as the 2-year distance learning diploma in sports nutrition offered by the International Olympic Committee. For more information refer to Sports Oracle: www.sportsoracle.com/Nutrition/Home/.

The Academy of Nutrition and Dietetics[157] describes the competencies of the sports dietitian to "provide medical nutrition therapy in direct care and design, implement, and manage safe and effective nutrition strategies that enhance lifelong health, fitness, and optimal physical performance." Roles and responsibilities of sports dietitians working with athletes are outlined in Table 4.

SUMMARY

The following summarizes the evidence presented in this position paper:

- Athletes need to consume energy that is adequate in amount and timing of intake during periods of high-intensity and/or long duration training to maintain health and maximize training outcomes. Low energy availability can result in unwanted loss of muscle mass; menstrual dysfunction and hormonal disturbances; sub-optimal bone density; an increased risk of fatigue, injury, and illness; impaired adaptation and a prolonged recovery process.
- The primary goal of the training diet is to provide nutritional support to allow the athlete to stay healthy and

injury-free while maximizing the functional and metabolic adaptations to a periodized exercise program that prepares him or her to better achieve the performance demands of their event. While some nutrition strategies allow the athlete to train hard and recover quickly, others may target an enhanced training stimulus or adaptation.

- The optimal physique, including body size, shape and composition (eg, muscle mass and body fat levels), depends upon the sex, age, and heredity of the athlete, and may be sport- and event-specific. Physique assessment techniques have inherent limitations of reliability and validity, but with standardized measurement protocols and careful interpretation of results, they may provide useful information. Where significant manipulation of body composition is required, it should ideally take place well before the competitive season to minimize the impact on event performance or reliance on rapid weight loss techniques.
- Body carbohydrate stores provide an important fuel source for the brain and muscle during exercise, and are manipulated by exercise and dietary intake. Recommendations for carbohydrate intake typically range from 3–10 g/kg BW/d (and up to 12 g/kg BW/d for extreme and prolonged activities), depending on the fuel demands of training or competition, the balance between performance and training adaptation goals, the athlete's total energy requirements and body composition goals. Targets should be individualized to the athlete and his or her event, and also periodized over the week, and training cycles of the seasonal calendar according to changes in exercise volume and the importance of high carbohydrate availability for different exercise sessions.
- Recommendations for protein intake typically range from 1.2–2.0 g/kg BW/d, but have more recently been expressed in terms of the regular spacing of intakes of modest amounts of high quality protein (0.3 g/kg body weight) after exercise and throughout the day. Such intakes can generally be met from food sources. Adequate energy is needed to optimize protein metabolism, and when energy availability is reduced (eg, to reduce body weight/fat), higher protein intakes are needed to support MPS and retention of fat-free mass.
- For most athletes, fat intakes associated with eating styles that accommodate dietary goals typically range from 20%–35% of total energy intake. Consuming ≤20% of energy intake from fat does not benefit performance and extreme restriction of fat intake may limit the food range needed to meet overall health and performance goals. Claims that extremely high-fat, carbohydrate-restricted diets provide a benefit to the performance of competitive athletes are not supported by current literature.
- Athletes should consume diets that provide at least the Recommended Dietary Allowance (RDA)/Adequate Intake (AI) for all micronutrients. Athletes who restrict energy intake or use severe weight-loss practices, eliminate complete food groups from their diet, or follow other extreme dietary philosophies are at greatest risk of micronutrient deficiencies.
- A primary goal of competition nutrition is to address nutrition-related factors that may limit performance by causing fatigue and a deterioration in skill or concentration over the course of the event. For example, in events that are dependent on muscle carbohydrate availability, meals eaten in the day(s) leading up to an event should provide sufficient carbohydrate to achieve glycogen stores that are commensurate with the fuel needs of the event. Exercise taper and a carbohydrate-rich diet (7–12 g/kg BW/d) can normalize muscle glycogen levels within ~ 24 hours, while extending this to 48 hours can achieve glycogen super-compensation.
- Foods and fluids consumed in the 1–4 hours prior to an event should contribute to body carbohydrate stores (particularly, in the case of early morning events to restore liver glycogen after the overnight fast), ensure appropriate hydration status and maintain gastrointestinal comfort throughout the event. The type, timing and amount of foods and fluids included in this pre-event meal and/or snack should be well trialed and individualized according to the preferences, tolerance, and experiences of each athlete.
- Dehydration/hypohydration can increase the perception of effort and impair exercise performance; thus, appropriate fluid intake before, during, and after exercise is important for health and optimal performance. The goal of drinking during exercise is to address sweat losses which occur to assist thermoregulation. Individualized fluid plans should be developed to use the opportunities to drink during a workout or competitive event to replace as much of the sweat loss as is practical; neither drinking in excess of sweat rate nor allowing dehydration to reach problematic levels. After exercise, the athlete should restore fluid balance by drinking a volume of fluid that is equivalent to ~125–150% of the remaining fluid deficit (eg, 1.25–1.5 L fluid for every 1 kg BW lost).
- An additional nutritional strategy for events of greater than 60 minutes duration is to consume carbohydrate according to its potential to enhance performance. These benefits are achieved via a variety of mechanisms which may occur independently or simultaneously and are generally divided into metabolic (providing fuel to the muscle) and central (supporting the central nervous system). Typically, an intake of 30–60 g/hour provides benefits by contributing to muscle fuel needs and maintaining blood glucose concentrations, although in very prolonged events (2.5+ h) or other scenarios where endogenous carbohydrate stores are substantially depleted, higher intakes (up to 90 g/h) are associated with better performance. Even in sustained high-intensity events of 45–75 min where there is little need for carbohydrate intake to play a metabolic role, frequent exposure of the mouth and oral cavity to small amounts of carbohydrate can still enhance performance via stimulation of the brain and central nervous system.
- Rapid restoration of performance between physiologically demanding training sessions or competitive events requires appropriate intake of fluids, electrolytes, energy, and carbohydrates to promote rehydration and restore muscle

TABLE 4. Sports dietitian roles and responsibilities.

Role of Sports Dietitian	Responsibilities
Assessment of nutritional needs and current dietary practices	• Energy intake, nutrients and fluids before, during and after training and competitions • Nutrition-related health concerns (eating disorders, food allergies or intolerances, gastrointestinal disturbances, injury management, muscle cramps, hypoglycemia, etc.) and body composition goals • Food and fluid intake as well as estimated energy expenditure during rest, taper and travel days • Nutritional needs during extreme conditions (eg, high altitude training, environmental concerns) • Adequacy of athlete's body weight and metabolic risk factors associated with low body weight • Supplementation practices • Basic measures of height, body weight, etc. with possible assessment of body composition
Interpretation of test results (eg, biochemistry, anthropometry)	• Blood, urine analysis, body composition and physiological testing results, including hydration status
Dietary prescription and education	• Dietary strategies to support behavior change for improvements with health, physical performance, body composition goals and/or eating disorders • Dietary recommendations prescribed relative to athlete's personal goals and chief concerns related to training, body composition, and/or competition nutrition, tapering, and/or periodized fat/weight loss • Quantity, quality, and timing for food and fluid intake before, during and after training and/or competition to enhance exercise training capacity, endurance and performance • Medical nutritional therapeutic advice pertaining to unique dietary considerations (eating disorders, food allergies, diabetes, gastrointestinal issues, etc.) • Menu planning, time management, grocery shopping, food preparation, food storage, food budgeting, food security, and recipe modification for training and/or competition days • Food selection related to travel, restaurants, and training and competition venue choices • Supplementation, ergogenic aids, fortified foods, etc. regarding legality, safety, and efficacy • Sport nutrition education, resource development and support may be with individual athletes, entire teams, and/or with coaches, athletic trainers, physiologists, food service staff, etc.
Collaboration and integration	• Contribution as a member of a multidisciplinary team within sport settings to integrate nutrition programming into a team or athlete's annual training and competition plan • Collaboration with the health care team/performance professionals (physicians, athletic trainer, physiologists, psychologists, etc.) for the performance management of athletes
Evaluation and professionalism	• Evaluation of scientific literature and provision of evidence-based assessment and application to athletic performance • Development of oversight of nutrition policies and procedures • Documentation of measurable outcomes of nutrition services • Recruitment and retention of clients and athletes in practice • Provision of reimbursable services (eg, diabetes medical nutrition therapy) • Promotion of career longevity for active individuals, collegiate and professional athletes • Service as a mentor for developing sports dietetics professionals • Maintenance of credential(s) by actively engaging in profession-specific continuing education activities

glycogen. A carbohydrate intake of ~1.0–1.2 g/kg/h, commencing during the early recovery phase and continuing for 4 to 6 hours, will optimize rates of resynthesis of muscle glycogen. The available evidence suggests that the early intake of high quality protein sources (0.25–0.3 g/kg BW) will provide amino acids to build and repair muscle tissue and may enhance glycogen storage in situations where carbohydrate intake is sub-optimal.

- In general, vitamin and mineral supplements are unnecessary for the athlete who consumes a diet providing high-energy availability from a variety of nutrient-dense foods. A multivitamin/mineral supplement may be appropriate in some cases when these conditions do not exist; for example, if an athlete is following an energy-restricted diet or is unwilling or unable to consume sufficient dietary variety. Supplementation recommendations should be individualized, realizing that targeted supplementation may be indicated to treat or prevent deficiency (eg, iron, vitamin D, etc.).
- Athletes should be counseled regarding the appropriate use of sports foods and nutritional ergogenic aids. Such products should only be used after careful evaluation for safety, efficacy, potency and compliance with relevant anti-doping codes and legal requirements.
- Vegetarian athletes may be at risk for low intakes of energy, protein, fat, creatine, carnosine, n-3 fatty acids, and key micronutrients such as iron, calcium, riboflavin, zinc, and vitamin B-12.

This Academy of Nutrition and Dietetics, Dietitians of Canada (DC), and American College of Sports Medicine (ACSM) position statement was adopted by the Academy House of Delegates Leadership Team on July 12, 2000 and reaffirmed on May 25, 2004 and February 15, 2011; approved by DC on November 17, 2015 and approved by the ACSM Board of Trustees on November 20, 2015. This position statement is in effect until December 31, 2019. Position papers should not be used to indicate endorsement of products or services.

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