from the association

Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and Athletic Performance

ABSTRACT

It is the position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine that physical activity, athletic performance, and recovery from exercise are enhanced by optimal nutrition. These organizations recommend appropriate selection of foods and fluids, timing of intake, and supplement choices for optimal health and exercise performance. This updated position paper couples a rigorous, systematic, evidence-based analysis of nutrition and performance-specific literature with current scientific data related to energy needs, assessment of body composition, strategies for weight change, nutrient and fluid needs, special nutrient needs during training and competition, the use of supplements and ergogenic aids, nutrition recommendations for vegetarian athletes, and the roles and responsibilities of sports dietitians. Energy and macronutrient needs, especially carbohydrate and protein, must be met during times of high physical activity to maintain body weight, replenish glycogen stores, and provide adequate protein to build and repair tissue. Fat intake should be sufficient to provide the essential fatty acids and fat-soluble vitamins, as well as contribute energy for weight maintenance. Although exercise performance can be affected by body weight and composition, these physical measures should not be a criterion for sports performance and daily weigh-ins are discouraged. Adequate food and fluid should be consumed before, during, and after exercise to help maintain blood glucose concentration during exercise, maximize exercise performance, and improve recovery time. Athletes should be well hydrated before exercise and drink enough fluid during and after exercise to balance fluid losses. Sports beverages containing carbohydrates and electrolytes may be consumed before, during, and after exercise to help maintain blood glucose concentration, provide fuel for muscles, and decrease risk of dehydration and hyponatremia. Vitamin and mineral supplements are not needed if adequate energy to maintain body weight is consumed from a variety of foods. However, athletes who restrict energy intake, use severe weight-loss practices, eliminate one or more food groups from their diet, or consume unbalanced diets with low micronutrient density, may require supplements. Because regulations specific to nutritional ergogenic aids are poorly enforced, they should be used with caution, and only after careful product evaluation for safety, efficacy, potency, and legality. A qualified sports dietitian and in particular in the United States, a Board Certified Specialist in Sports Dietetics, should provide individualized nutrition direction and advice subsequent to a comprehensive nutrition assessment.

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This American Dietetic Association (ADA) position paper uses ADA's Evidence Analysis Process and information from ADA's Evidence Analysis Library. Similar information is also available from Dietitians of Canada's Practice-based Evidence in Nutrition. 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 ADA's Evidence Analysis Process at http://adaeal.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=Grade Is Not Assignable (because there is no evidence to support or refute the conclusion).

Evidence-based information for this and other topics can be found at www.adaevidencelibrary.com and www.dieteticsatwork.com/pen and subscriptions for non-ADA members are available for purchase at https://www.adaevidencelibrary.com/store.cfm. Subscriptions for Dietitians of Canada and non-Dietitians of Canada members are available for Practice-based Evidence in Nutrition at http://www.dieteticsatwork.com/pen_order.asp.

POSITION STATEMENT

It is the position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine that physical activity, athletic performance, and recovery from exercise are enhanced by optimal nutrition. These organizations recommend appropriate selection of food and fluids, timing of intake, and sup-

plement choices for optimal health and exercise performance.

The following key points summarize the current energy, nutrient, and fluid recommendations for active adults and competitive athletes. These general recommendations can be adjusted by sports nutrition experts to accommodate the unique concerns of individual athletes regarding health, sports, nutrient needs, food preferences, and body weight and body composition goals.

- Athletes need to consume adequate energy during periods of high-intensity and/or long-duration training to maintain body weight and health and maximize training effects. Low energy intakes can result in loss of muscle mass; menstrual dysfunction; loss of or failure to gain bone density; an increased risk of fatigue, injury, and illness; and a prolonged recovery process.
- Body weight and composition should not be the sole criterion for participation in sports; daily weigh-ins are discouraged. Optimal body fat levels depend upon the sex, age, and heredity of the athlete, and may be sport-specific. Body fat assessment techniques have inherent variability and limitations. Preferably, weight loss (fat loss) should take place during the off-season or begin before the competitive season and involve a qualified sports dietitian.
- Carbohydrate recommendations for athletes range from 6 to 10 g/kg (2.7 to 4.5 g/lb) body weight per day. Carbohydrates maintain blood glucose levels during exercise and replace muscle glycogen. The amount required depends upon the athlete's total daily energy expenditure, type of sport, sex, and environmental conditions.
- Protein recommendations for endurance and strength-trained athletes range from 1.2 to 1.7 g/kg (0.5 to 0.8 g/lb) body weight per day. These recommended protein intakes can generally be met through diet alone, without the use of protein or amino acid supplements. Energy intake sufficient to maintain body weight is necessary for optimal protein use and performance.
- Fat intake should range from 20% to 35% of total energy intake. Consuming ≤20% of energy from fat does not benefit performance. Fat, which is a source of energy, fat-soluble vitamins, and essential fatty acids, is important in the diets of athletes. High-fat diets are not recommended for athletes.
- Athletes who restrict energy intake or use severe weight-loss practices, eliminate one or more food groups from their diet, or consume high- or low-carbohydrate diets of low micronutrient density are at greatest risk of micronutrient deficiencies. Athletes should consume diets that provide at least the Recommended Dietary Allowance (RDA) for all micronutrients.
- Dehydration (water deficit in excess of 2% to 3% body mass) decreases exercise performance; thus, adequate fluid intake before, during, and after exercise is important for health and optimal performance. The goal of drinking is to prevent dehydration from occurring during exercise and individuals should not drink in excess of sweating rate. After exercise, the athlete should drink adequate fluids to replace sweat losses during exercise, approximately 16 to 24 oz (450 to 675 mL) fluid for every pound (0.5 kg) of body weight lost during exercise.
- Before exercise, a meal or snack should provide sufficient fluid to maintain hydration, be relatively low in fat and fiber to facilitate gastric emptying and minimize gastrointestinal distress, be relatively high in carbohydrate to maximize maintenance of blood glucose, be moderate in protein, be composed of familiar foods, and be well tolerated by the athlete.
- During exercise, primary goals for nutrient consumption are to replace fluid losses and provide carbohydrates (approximately 30 to 60 g per hour) for maintenance of blood glucose levels. These nutrition guidelines are especially important for endurance events lasting longer than an hour when an athlete has not consumed adequate food or fluid before exercise, or if an athlete is exercising in an extreme environment (eg, heat, cold, or high altitude).
- After exercise, dietary goals are to provide adequate fluids, electrolytes, energy, and carbohydrates to replace muscle glycogen and ensure rapid recovery. A carbohydrate intake of ~1.0 to 1.5 g/kg (0.5 to 0.7 g/lb) body weight during the first 30 minutes and again every 2 hours for 4 to 6 hours will be adequate to replace glycogen stores. Protein consumed after exercise will provide amino acids for building and repair of muscle tissue.
- In general, no vitamin and mineral supplements are required if an athlete is consuming adequate energy from a variety of foods to maintain body weight. Supplementation recommendations unrelated to exercise, such as folic acid for women of childbearing potential, should be followed. A multivitamin/mineral supplement may be appropriate if an athlete is dieting, habitually eliminating foods or food groups, is ill or recovering from injury, or has a specific micronutrient deficiency. Single-nutrient supplements may be appropriate for a specific medical or nutritional reason (eg, iron supplements to correct iron deficiency anemia).
- Athletes should be counseled regarding the appropriate use of ergogenic aids. Such products should only be used after careful evaluation for safety, efficacy, potency, and legality.
- Vegetarian athletes may be at risk for low intakes of energy, protein, fat, and key micronutrients such as iron, calcium, vitamin D, riboflavin, zinc, and vitamin B-12. Consultation with a sports dietitian is recommended to avoid these nutrition problems.

EVIDENCE-BASED ANALYSIS

Studies used in the development of this position paper were identified from the PubMed database maintained by the National Library of Medicine and CENTRAL database, as well as through research articles and literature reviews. Five topic-specific questions were identified for evidence-based analysis (Figure 1) and incorporated into this position, updating the prior position on nutrition and performance (1). Search terms used were athlete, performance, power, strength, endurance, or competition and macronutrient, meal, carbohydrate, fat, protein, or energy. For the purpose of this analysis, inclusion criteria were adults aged 18 to 40 years; all sport settings; and trained athletes, athletes in training, or individuals regularly exercising. Since the grading system used provides allow-

Topic	Question
• Energy balance and body composition	What is the relationship between energy balance/imbalance, body composition, and/or weight management and athletic performance?
• Training	What is the evidence to support a particular meal timing, energy intake, and macronutrient intake for optimal athletic performance during training?
• Competition	What is the evidence to support a particular meal timing, energy intake, and macronutrient intake for optimal athletic performance during competition during the 24 hours before competition?
	What is the evidence to support a particular meal timing, energy intake, and macronutrient intake for optimal athletic performance during competition?
• Recovery	What is the evidence to support a particular meal timing, energy intake, and macronutrient intake for optimal athletic performance during recovery?

Figure 1. Specific topics and the respective questions used for the evidence analysis sections of the American Dietetic Association, Dietitians of Canada, and American College of Sports Medicine position on nutrition and athletic performance.

ances for consideration of study design, the evidence-based analysis was not limited to randomized controlled trials. Study design preferences were randomized controlled trials or clinical controlled studies; large nonrandomized observational studies; and cohort, case-control studies. All sample sizes were included and study drop out rate could not exceed 20%. The publication range for the evidence-based analysis spanned 1995-2006. If an author was included on more than one review article or primary research article which were similar in content, the most recent paper was accepted and earlier versions rejected. However, when an author was included on more than one review article or primary research article for which content differed, then both reviews could be accepted for analysis.

The following exclusion criteria were applied to all identified studies:

- adults older than age 40 years, young adults younger than age 18 years, infants, children, and adolescents;
- settings not related to sports;
- nonathletes;
- critical illness and other diseases and conditions;
- drop out rates >20%;
- publication before 1995;
- studies by same author that were similar in content; and
- articles not in English.

Conclusion statements were formulated summarizing the strength of evidence with respect to each question (Figure 1). The strength of the evidence was graded using the following elements: quality, consistency across studies, quantity, and generalizability. A more detailed description of the methodology used for this evidence-based analysis may be found on the American Dietetic Association Web site at www.eatright.org/cps/rde/xchg/ada/hs.xsl/8099_ENU_HTML.htm.

ENERGY METABOLISM

Energy expenditure must equal energy intake to achieve energy balance. The energy systems used during exercise for muscular work include the phosphagen and glycolytic (both anaerobic) and the oxidative (aerobic) pathways. The phosphagen system is used for events lasting no longer than a few seconds and of high intensity. Adenosine triphosphate (ATP) and creatine phosphate provide the readily available energy present within the muscle. The amount of ATP present in skeletal muscles (~5 mmol/kg wet weight) is not sufficient to provide a continuous supply of energy, especially at high exercise intensities. Creatine phosphate is an ATP reserve in muscle that can be readily converted to sustain activity for ~3 to 5 minutes (2). The amount of creatine phosphate available in skeletal muscle is ~4 times greater than ATP, and therefore, is the primary fuel used for high intensity, short duration activities such as the clean and jerk in weight lifting, or fast break in basketball.

The anaerobic glycolytic pathway uses muscle glycogen and glucose that are rapidly metabolized anaerobically through the glycolytic cascade. This pathway supports events lasting 60 to 180 seconds. Approximately 25% to 35% of total muscle glycogen stores are used during a single 30-second sprint or resistance exercise bout. Neither the phosphagen nor the glycolytic pathway can sustain the rapid provision of energy to allow muscles to contract at a very high rate for events lasting greater than ~2 to 3 minutes.

The oxidative pathway fuels events lasting longer than 2 to 3 minutes. The major substrates include muscle and liver glycogen, intramuscular, blood, and adipose tissue triglycerides, and negligible amounts of amino acids from muscle, blood, liver, and the gut. Examples of events for which the major fuel pathway is the oxidative pathway include a 1,500-meter run, marathon, half-marathon, and endurance cycling or ≥500 meter swimming events. 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. Only the aerobic pathway can produce large amounts of ATP over time via the Kreb's cycle and the electron transport system. The greater dependence upon aerobic pathways does not occur abruptly, nor is one pathway ever relied on exclusively. The intensity, duration, frequency, type of activity, sex, and fitness level of the individual, as well as prior nutrient intake and energy stores, determine when the crossover from primarily aerobic to anaerobic pathways occurs (2).

Conversion of Energy Sources Over Time

Approximately 50% to 60% of energy during 1 to 4 hours of continuous exercise at 70% of maximal oxygen capacity is derived from carbohydrates and the rest from free fatty acid oxidation (3). A greater proportion of energy comes from oxidation of free fatty acids, primarily those from muscle triglycerides as intensity of the exercise decreases (3). Training does not alter the total amount of energy expended but rather the proportion of energy derived from carbohydrates and fat (3). As a result of aerobic training, the energy derived from fat increases and from carbohydrates decreases. A trained individual uses a greater percentage of fat than an untrained person does at the same workload (2). Long-chain fatty aids derived from stored muscle triglycerides are the preferred fuel for aerobic exercise for individuals involved in mild- to moderate-intensity exercise (4).

Adult man
662−9.53 (age in years)+PA[a] [15.91 (weight in kilograms)+539.6 (height in meters)].

Adult woman
354−6.91 (age in years)+PA [9.36 (weight in kilograms)+726 (height in meters)]

PA level	
1.0-1.39	Sedentary, typical daily living activities (eg, household tasks, walking to bus).
1.4-1.59	Low active, typical daily living activities plus 30-60 minutes of daily moderate activity (eg, walking at 5-7 km/h).
1.6-1.89	Active, typical daily living activities plus 60 minutes of daily moderate activity.
1.9-2.5	Very active, typical daily activities plus at least 60 minutes of daily moderate activity plus an additional 60 minutes of vigorous activity or 120 minutes of moderate activity.

Figure 2. The Dietary Reference Intake (DRI) method for estimating energy requirement for adults. Adapted from reference 17. [a]PA=physical activity.

ENERGY REQUIREMENTS

Meeting energy needs is a nutrition priority for athletes. Optimum athletic performance is promoted by adequate energy intake. This section provides information necessary to determine energy balance for an individual. Energy balance occurs when energy intake (the sum of energy from foods, fluids, and supplement products) equals energy expenditure or the sum of energy expended as basal metabolic rate; the thermic effect of food; and the thermic effect of activity, which is the energy expended in planned physical activity and nonexercise activity thermogenesis (5). Spontaneous physical activity is also included in the thermic effect of activity.

Athletes need to consume enough energy to maintain appropriate weight and body composition while training for a sport (6). Although usual energy intakes for many intensely training female athletes might match those of male athletes per kilogram body weight, some female athletes may consume less energy than they expend. Low energy intake (eg, <1,800 to 2,000 kcal/day) for female athletes is a major nutritional concern because a persistent state of negative energy balance can lead to weight loss and disruption of endocrine function (7-10).

Inadequate energy intake relative to energy expenditure compromises performance and negates the benefits of training. With limited energy intake, fat and lean tissue will be used for fuel by the body. Loss of lean tissue mass results in the loss of strength and endurance, as well as compromised immune, endocrine, and musculoskeletal function (11). In addition, chronically low energy intake results in poor nutrient intake, particularly of the micronutrients and may result in metabolic dysfunctions associated with nutrient deficiencies as well as lowered resting metabolic rate. The newer concept of energy availability, defined as dietary intake minus exercise energy expenditure normalized to fat-free mass (FFM), is the amount of energy available to the body to perform all other functions after exercise training expenditure is subtracted. Many researchers have suggested that 30 kcal/kg FFM/day might be the lower threshold of energy availability for women (12-15).

Estimation of energy needs of athletes and active individuals can be done using a variety of methods. The *Dietary Guidelines for Americans 2005* (16) and the Dietary Reference Intakes (15,17) provide energy recommendations for men and women who are slightly to very active that are based on predictive equations developed using the doubly labeled water technique, which can also be used to estimate energy needs of athletes (Figure 2).

Energy expenditure for different types of exercise is dependent upon the duration, frequency, and intensity of the exercise, the sex of the athlete, and prior nutritional status. Heredity, age, body size, and FFM also influence energy expenditure. The more energy used in activity, the more energy needed to achieve energy balance.

Typical laboratory facilities are usually not equipped to determine total energy expenditure. Therefore, predictive equations are often used to estimate basal metabolic rate or resting metabolic rate. The two prediction equations considered to most closely estimate energy expenditure are the Cunningham equation (18) and the Harris-Benedict equation (19). Because the Cunningham equation requires that lean body mass be known, sports dietitians typically use the Harris-Benedict equation. To estimate total energy expenditure, basal metabolic rate or resting metabolic rate is then multiplied by the appropriate activity factor of 1.8 to 2.3 (representing moderate to very heavy physical activity levels, respectively). Numeric guidelines such as these (8) only provide an approximation of the average energy needs of an individual athlete. An alternative method for estimating exercise energy expenditure is to use metabolic equivalents recorded over a 24-hour period (20). Any of these methods can be used to estimate energy expenditure for the determination of energy intake requirements and provide a sports dietitian with a basis to guide an athlete or active individual in meeting their energy needs.

BODY COMPOSITION

Body composition and body weight are two of the many factors that contribute to optimal exercise performance. Taken together, these two factors may affect an athlete's potential for success for a given sport. Body weight can influence an athlete's speed, endurance, and power, whereas body composition can affect an athlete's strength, agility, and appearance. A lean body (ie, one with greater muscle/fat ratio) is often advantageous in sports where speed is involved.

Athletic performance cannot be accurately predicted based solely on body weight and composition given that many factors affect body composition (21). Some sports dictate that athletes make changes in body weight and composition that may not be best for the individual athlete. Athletes who participate in weight-class sports—such as wrestling or lightweight rowing—may be required to lose or gain weight to qualify for a specific weight category. Athletes who participate in body conscious sports such as dance, gymnastics, figure skating, or diving, may be pressured to lose weight and body fat to have a lean physique, although their current weight for health and performance is appropriate. With extreme energy restrictions, losses of both muscle and fat mass may adversely influence an athlete's performance.

Individualized assessment of an athlete's body composition and body weight or body image may be advantageous for improvement of athletic performance. Age, sex, genetics, and the requirements of the sport are factors that influence an individual athlete's body composition. An optimal competitive body weight and relative body fatness should be determined when an athlete is healthy and performing at his or her best.

Methodology and equipment to perform body composition assessments must be accessible and cost effective. Not all of the following methods meet these criteria for the practitioner. In addition, athletes and coaches should know that there are errors associated with all body composition techniques and that it is not appropriate to set a specific body fat percentage goal for an individual athlete. Rather, a range of target percentages of body fat values should be recommended.

Assessment Methodology

Three levels of assessment techniques are used to assess body composition (22). Direct assessment based on analysis of cadavers, although not used in clinical practice, is designated as a Level 1 technique. The other two technique levels are indirect assessments (Level II) and doubly indirect assessments (Level III). Hydrodensitometry, or underwater weighing, dual-energy x-ray absorptiometry and air displacement plethysmography are Level II techniques, and skinfold measurements and bioelectrical impedance analysis (BIA) are Level III techniques. Level II and Level III techniques are used in practice by sports dietitians.

Underwater weighing, once considered the criterion standard, is no longer common. dual-energy x-ray absorptiometry, originally developed to assess bone mineral density, can be used for body composition analysis (21). Although dual-energy x-ray absorptiometry is fairly accurate, quick, and noninvasive, the cost of and access to the instrument limits its utility in practice. Air displacement plethysmography (BodPod, Life Measurement, Inc, Concord, CA) is also used to determine body composition by body density (22), and body fat percentage is calculated using the Siri (23) or Brozek and colleagues (24) equations. Although this method provides valid and reliable assessment of body composition, it may underestimate body fat in adults and children by 2% to 3% (25).

Two of the most commonly used Level III methods are skinfold measurements and BIA. In addition to measures of body weight, height, wrist and girth circumferences, skinfold measurements are routinely used by sports dietitians to assess body composition. Usually, seven skinfold sites are used, including abdominal, biceps, front thigh, medial calf, subscapular, supraspinale, and triceps. The standard techniques and definitions of each of these sites are provided by Heymsfield and colleagues and Marfell-Jones and colleagues (22). Prediction equations using skinfold measurements to determine body fat content are numerous (22). Approximately 50% to 70% of the variance in body density is accounted for by this measurement. In addition, population differences limit the ability to interchange the prediction equations, standardization of skinfold sites varies, and skinfold measurement techniques vary from investigator to investigator. Even the skinfold caliper is a source of variability (22). Despite the inherent problems of skinfold measurement, this technique remains a method of choice because it is convenient and inexpensive. The US Olympic Committee is using the International Society for Advances in Kinanthropometry techniques (26) as efforts are underway to standardize measures worldwide. The US Olympic Committee advocates using the sum of seven skinfolds (millimeters) based on International Society for Advances in Kinanthropometry landmarks, marking skinfold sites on the body, reporting duplicate measures, and communicating the results as a range, rather than percentage body fat.

BIA is based on the principle that an electrical signal is more easily conducted through lean tissue than fat or bone (22). Fat mass is estimated by subtracting the BIA determined estimate of FFM from total body mass. Whole body resistance to the flow of an electrical current conducted through the body by electrodes placed on wrists and ankles can provide fairly accurate estimates of total body water and FFM (22). BIA is dependent on a number of factors that can cause error in the measurement and must be taken into account to obtain a fairly accurate estimate. Hydration status is the most important factor that may alter the estimated percentage body fat. The prediction accuracy of BIA is similar to skinfold assessments but BIA may be preferable because it does not require the technical skill associated with skinfold measurements (27). Currently, upper and lower body impedance devices have been developed but have not been evaluated in an athletic population.

Body Composition and Sports Performance

Body fat percentage of athletes varies depending on the sex of the athlete and the sport. The estimated minimal level of body fat compatible with health is 5% for men and 12% for women (22); however, optimal body fat percentages for an individual athlete may be much higher than these minimums and should be determined on an individual basis. The International Society for Advances in Kinanthropometry sum of seven skinfolds indicates that the range of values for the athletic population is 30 to 60 mm for men and 40 to 90 mm for women (26). Body composition analysis should not be used as a criterion for selection of athletes for athletic teams. Weight management interventions should be thoughtfully designed to avoid detrimental outcomes

Setting and monitoring goals

- Set realistic weight and body composition goals. Ask the athlete:
  - What is the maximum weight that you would find acceptable?
  - What was the lowest weight you maintained without constant dieting?
  - How did you derive your goal weight?
  - At what weight and body composition do you perform best?
- Encourage less focus on the scale and more on healthful habits such as stress management and making good food choices.
- Monitor progress by measuring changes in exercise performance and energy level, the prevention of injuries, normal menstrual function, and general overall well-being.
- Help athletes to develop lifestyle changes that maintain a healthful weight for themselves—not for their sport, for their coach, for their friends, for their parents, or to prove a point.

Suggestions for food intake

- Low energy intake will not sustain athletic training. Instead, decreases in energy intake of 10% to 20% of normal intake will lead to weight loss without the athlete feeling deprived or overly hungry. Strategies such as substituting lower-fat foods for whole-fat foods, reducing intake of energy-dense snacks, portion awareness, and doing activities other than eating when not hungry can be useful.
- If appropriate, athletes can reduce fat intake but need to know that a lower-fat diet will not guarantee weight loss unless a negative energy balance (reduced energy intake and increased energy expenditure) is achieved. Fat intake should not be decreased below 15% of total energy intake because some fat is essential for good health.
- Emphasize increased intake of whole grains and cereals, and legumes.
- Five or more daily servings of fruits and vegetables provide nutrients and fiber.
- Dieting athletes should not skimp on protein and need to maintain adequate calcium intakes. Accordingly, use of low-fat dairy products and lean meats, fish, and poultry is suggested.
- A variety of fluids—especially water—should be consumed throughout the day, including before, during, and after exercise. Dehydration as a means of reaching a body-weight goal is contraindicated.

Other weight management strategies

- Advise athletes against skipping meals (especially breakfast) and allowing themselves to become overly hungry. They should be prepared for times when they might get hungry, including keeping nutritious snacks available for those times.
- Athletes should not deprive themselves of favorite foods or set unrealistic dietary rules or guidelines. Instead, dietary goals should be flexible and achievable. Athletes should remember that all foods can fit into a healthful lifestyle. Developing list of "good" and "bad" foods is discouraged.
- Help athletes identify their own dietary weaknesses and plan strategies for dealing with them.
- Remind athletes that they are making lifelong dietary changes to sustain a healthful weight and optimal nutritional status rather than going on a short-term diet.

Figure 3. Weight management strategies for athletes. (Adapted from: Manore MM. Chronic dieting in active women: What are the health consequences? *Women's Health Issues.* 1996;6:332-341. Copyright 1996, with permission from Elsevier.)

with specific regard for performance, as well as body composition (ie, loss of lean body mass). See Figure 3 for practical guidelines for weight management of athletes.

Conclusion Statement. Four studies have reported inconclusive findings related to the effects of energy and protein restriction on athletic performance, but carbohydrate restriction has been shown to be detrimental. For weight class athletes, two studies show that weight loss preceding athletic competition may have no significant effect on measures of performance, depending on refeeding protocol. **Evidence Grade III=Limited** (www.adaevidencelibrary.com/conclusion.cfm?conclusion_statement_id=250448).

MACRONUTRIENT REQUIREMENTS FOR EXERCISE

Athletes do not need a diet substantially different from that recommended in the 2005 Dietary Guidelines (16) and Eating Well with Canada's Food Guide (28). Although high-carbohydrate diets (more than 60% of energy intake) have been advocated in the past, caution is recommended in using specific percentages as a basis for meal plans for athletes. For example, when energy intake is 4,000 to 5,000 kcal/day, even a diet containing 50% of energy from carbohydrate will provide 500 to 600 g carbohydrate (or approximately 7 to 8 g/kg [3.2 to 3.6 g/lb] for a 70-kg [154 lb] athlete), an amount sufficient to maintain muscle glycogen stores from day to day (29). Similarly, if protein intake for this plan was 10% of energy intake, absolute protein intake (100 to 125 g/day) could exceed the recommended protein intake for athletes (1.2 to 1.7 g/kg/day or 84 to 119 g in a 70-kg athlete). Conversely, when energy intake is less than 2,000 kcal/day, a diet providing 60% of energy from carbohydrate may not be sufficient to maintain optimal carbohydrate stores (4 to 5 g/kg or 1.8 to 2.3 g/lb) in a 60-kg (132 lb) athlete.

Protein

Protein metabolism during and following exercise is affected by sex, age, intensity, duration, and type of exercise, energy intake, and carbohydrate availability. More detailed reviews of these factors and their relationship to protein metabolism and needs of active individuals can be found elsewhere (30,31). The current RDA is 0.8 g/kg body weight and the Acceptable Macronutrient Distribution Range for protein intake for adults older than age 18 years is 10% to 35% of total energy (15). Because there is not a strong body of evidence documenting that additional dietary protein is needed by healthy adults who undertake endurance or resistance exercise, the current Dietary Reference

Intakes for protein and amino acids does not specifically recognize the unique needs of routinely active individuals and competitive athletes. However, recommending protein intakes in excess of the RDA to maintain optimum physical performance is commonly done in practice.

Endurance Athletes. An increase in protein oxidation during endurance exercise, coupled with nitrogen balance studies, provides the basis for recommending increased protein intakes for recovery from intense endurance training (32). Nitrogen balance studies suggest that dietary protein intake necessary to support nitrogen balance in endurance athletes ranges from 1.2 to 1.4 g/kg/day (29-31). These recommendations remain unchanged even though recent studies have shown that protein turnover may become more efficient in response to endurance exercise training (29,32). Ultraendurance athletes who engage in continuous activity for several hours or consecutive days of intermittent exercise should also consume protein at, or slightly above 1.2 to 1.4 g/kg/day (32). Energy balance, or the consumption of adequate energy, particularly carbohydrates, to meet those expended, is important to protein metabolism so that amino acids are spared for protein synthesis and not oxidized to assist in meeting energy needs (33,34). In addition, discussion continues as to whether sex differences in protein-related metabolic responses to exercise exist (35,36).

Strength Athletes. Resistance exercise may necessitate protein intake in excess of the RDA, as well as that needed for endurance exercise, because additional protein, essential amino acids in particular, is needed along with sufficient energy to support muscle growth (30,31). This is particularly true in the early phase of strength training when the most significant gains in muscle size occurs. The amount of protein needed to maintain muscle mass may be lower for individuals who routinely resistance train due to more efficient protein utilization (30,31). Recommended protein intakes for strength-trained athletes range from approximately 1.2 to 1.7 g/kg/day (30,32).

Protein and Amino Acid Supplements. High-protein diets have been popular throughout history. Although earlier investigations in this area involved supplementation with individual amino acids (37,38) more recent work has shown that intact, high-quality proteins such as whey, casein, or soy are effectively used for the maintenance, repair, and synthesis of skeletal muscle proteins in response to training (39). Protein or amino acids consumed in close proximity to strength and endurance exercise can enhance maintenance of, and net gains in, skeletal muscle (39,40). Because protein or amino acid supplementation has not been shown to positively influence athletic performance (41,42), recommendations regarding protein supplementation are conservative and directed primarily at optimizing the training response to and the recovery period following exercise. From a practical perspective, it is important to conduct a thorough nutrition assessment specific to an athlete's goals before recommending protein powders and amino acid supplements to athletes.

Fat

Fat is a necessary component of a normal diet, providing energy and essential elements of cell membranes and associated nutrients such as vitamins A, D, and E. The Acceptable Macronutrient Distribution Range for fat is 20% to 35% of energy intake (17). The 2005 Dietary Guidelines (16) and Eating Well with Canada's Food Guide (28) make recommendations that the proportion of energy from fatty acids be 10% saturated, 10% polyunsaturated, and 10% monounsaturated and include sources of essential fatty acids. Athletes should follow these general recommendations. Careful evaluation of studies suggesting a positive effect of consuming diets for which fat provides ≥70% of energy intake on athletic performance (43,44) does not support this concept (45).

VITAMINS AND MINERALS

Micronutrients play an important role in energy production, hemoglobin synthesis, maintenance of bone health, adequate immune function, and protection of body against oxidative damage. They assist with synthesis and repair of muscle tissue during recovery from exercise and injury. Exercise stresses many of the metabolic pathways where micronutrients are required, and exercise training may result in muscle biochemical adaptations that increase micronutrient needs. Routine exercise may also increase the turnover and loss of these micronutrients from the body. As a result, greater intakes of micronutrients may be required to cover increased needs for building, repair, and maintenance of lean body mass in athletes (46).

The most common vitamins and minerals found to be of concern in athletes' diets are calcium and vitamin D, the B vitamins, iron, zinc, magnesium, as well as some antioxidants such as vitamins C and E, beta carotene, and selenium (46-50). Athletes at greatest risk for poor micronutrient status are those who restrict energy intake or have severe weight loss practices, who eliminate one or more of the food groups from their diet, or who consume unbalanced and low micronutrient-dense diets. These athletes may benefit from a daily multivitamin/mineral supplement. Use of vitamin and mineral supplements does not improve performance in individuals consuming nutritionally adequate diets (46-48,50).

B Vitamins: Thiamin, Riboflavin, Niacin, B-6, Pantothenic Acid, Biotin, Folate, and B-12

Adequate intake of B vitamins is important to ensure optimum energy production and the building and repair of muscle tissue (48,51). The B-complex vitamins have two major functions directly related to exercise. Thiamin, riboflavin, niacin, pyridoxine (B-6), pantothenic acid, and biotin are involved in energy production during exercise (46,51), whereas folate and B-12 are required for the production of red blood cells, for protein synthesis, and in tissue repair and maintenance including the central nervous system. Of the B vitamins, riboflavin, pyridoxine, folate and B-12 are frequently low in female athletes' diets, especially those who are vegetarian or have disordered eating patterns (47,48).

Limited research has been conducted to examine whether exercise increases the need for the B-complex vitamins (46,48). Some data suggest that exercise may increase the need for these vitamins as much as twice the current recommended amount

(48); however, these increased needs can generally be met with higher energy intakes. Although short-term marginal deficiencies of B vitamins have not been observed to affect performance, severe deficiency of B-12, folate, or both may result in anemia and reduced endurance performance (46,47,52). Therefore, it is important that athletes consume adequate amounts of these micronutrients to support their efforts for optimal performance and health.

Vitamin D

Vitamin D is required for adequate calcium absorption, regulation of serum calcium and phosphorus levels, and promotion of bone health. Vitamin D also regulates the development and homeostasis of the nervous system and skeletal muscle (53-55). Athletes who live at northern latitudes or who train primarily indoors throughout the year, such as gymnasts and figure skaters, are at risk for poor vitamin D status, especially if they do not consume foods fortified with vitamin D (50,56,57). These athletes would benefit from supplementation with vitamin D at the Dietary Reference Intake level (5 μg/day or 200 IU for ages 19 to 49 years) (54,56,58-61). A growing number of experts advocate that the RDA for vitamin D is not adequate (53,62,63).

Antioxidants: Vitamins C and E, Beta Carotene, and Selenium

The antioxidant nutrients, vitamins C and E, beta carotene, and selenium, 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 exercise produces a constant "oxidative stress" on the muscles and other cells (49) leading to lipid peroxidation of membranes. Although acute exercise may increase levels of lipid peroxide byproducts (64), habitual exercise has been shown to result in an augmented antioxidant system and reduced lipid peroxidation (50,65). Thus, a well-trained athlete may have a more developed endogenous antioxidant system than a sedentary person. Whether exercise increases the need for antioxidant nutrients remains controversial. There is little evidence that antioxidant supplements enhance physical performance (49,50,64,66). Athletes at greatest risk for poor antioxidant intakes are those following a low-fat diet, restricting energy intakes, or limiting dietary intakes of fruits, vegetables, and whole grains (29,66).

The evidence that a combination of antioxidants or single antioxidants such as vitamin E may be helpful in reducing inflammation and muscle soreness during recovery from intense exercise remains unclear (42,67). Although the ergogenic potential of vitamin E with regard to physical performance has not been clearly documented, endurance athletes may have a higher need for this vitamin. Indeed, vitamin E supplementation has been shown to reduce lipid peroxidation during aerobic/endurance exercise and have a limited effect with strength training (66). There is some evidence that vitamin E may attenuate exercise-induced DNA damage and enhance recovery in certain active individuals; however, more research is needed (66). Athletes should be advised not to exceed the Tolerable Upper Intake Levels for antioxidants because higher doses could be pro-oxidative with potential negative effects (46,64,68).

Vitamin C supplements do not appear to have an ergogenic effect if the diet provides adequate amounts of this nutrient. Because strenuous and prolonged exercise has been shown to increase the need for vitamin C, physical performance can be compromised with marginal vitamin C status or deficiency. Athletes who participate in habitual prolonged, strenuous exercise should consume 100 to 1,000 mg vitamin C daily (47,69,70).

Minerals: Calcium, Iron, Zinc, and Magnesium

The primary minerals low in the diets of athletes, especially female athletes, are calcium, iron, zinc, and magnesium (47). Low intakes of these minerals are often due to energy restriction or avoidance of animal products (55).

Calcium. Calcium is especially important for growth, maintenance, and repair of bone tissue; maintenance of blood calcium levels, regulation of muscle contraction, nerve conduction, and normal blood clotting. Inadequate dietary calcium and vitamin D increase the risk of low bone-mineral density and stress fractures. Female athletes are at greatest risk for low bone-mineral density if energy intakes are low, dairy products and other calcium-rich foods are inadequate or eliminated from the diet, and menstrual dysfunction is present (47,52,55,71-73).

Supplementation with calcium and vitamin D should be determined after nutrition assessment. Current recommendations for athletes with disordered eating, amenorrhea, and risk for early osteoporosis are 1,500 mg elemental calcium and 400 to 800 IU of vitamin D per day (50,72,73).

Iron. Iron is required for the formation of oxygen-carrying proteins, hemoglobin and myoglobin, and for enzymes involved in energy production (50,74). Oxygen carrying capacity is essential for endurance exercise as well as normal function of the nervous, behavioral, and immune systems (64,74). Iron depletion (low iron stores) is one of the most prevalent nutrient deficiencies observed among athletes, especially women (75). Iron deficiency, with or without anemia, can impair muscle function and limit work capacity (47,58,75,76). Iron requirements for endurance athletes, especially distance runners, are increased by approximately 70% (58,74). Athletes who are vegetarian or regular blood donors should aim for an iron intake greater than their respective RDA (ie, >18 mg and >8 mg, for women and men, respectively) (58,75).

The high incidence of iron depletion among athletes is usually attributed to inadequate energy intake. Other factors that can affect iron status include vegetarian diets that have poor iron availability, periods of rapid growth, training at high altitudes, increased iron losses in sweat, feces, urine, menstrual blood, intravascular hemolysis, foot-strike hemolysis, regular blood donation, or injury (50,75,77). Athletes, especially women, long-distance runners, adolescents, and vegetarians should be screened periodically to assess and monitor iron status (75,77,78).

Because reversing iron deficiency anemia can require 3 to 6 months, it is advantageous to begin nutrition intervention before iron deficiency anemia develops (47,75). Although depleted iron stores (low serum ferritin) are more prevalent in female athletes, the incidence of iron deficiency anemia in athletes is similar to that of the nonathlete female population (50,75,77). Chronic iron deficiency, with or without anemia, that results from consistently poor iron intake can negatively affect health, physical and mental performance, and warrants prompt medical intervention and monitoring (76,78).

Some athletes may experience a transient decrease in serum ferritin and hemoglobin at the initiation of training due to hemodilution subsequent to an increase in plasma volume known as "dilutional" or "sports anemia" and may not respond to nutrition intervention. These changes appear to be a beneficial adaptation to aerobic training that do not negatively affect performance (50).

In athletes who are iron deficient, iron supplementation not only improves blood biochemical measures and iron status but also increases work capacity as evidenced by increasing oxygen uptake, reducing heart rate, and decreasing lactate concentration during exercise (47). There is some evidence that athletes who are iron deficient but do not have anemia may benefit from iron supplementation (50,75). Recent findings provide additional support for improved performance (eg, less skeletal muscle fatigue) when iron supplementation was prescribed as 100 mg ferrous sulfate for 4-6 weeks (76). Improving work capacity and endurance, increasing oxygen uptake, reduced lactate concentrations, and reduced muscle fatigue are benefits of improved iron status (50).

Zinc. Zinc plays a role in growth, building and repair of muscle tissue, energy production, and immune status. Diets low in animal protein, high in fiber, and vegetarian diets, in particular, are associated with decreased zinc intake (50,52). Zinc status has been shown to directly affect thyroid hormone levels, basal metabolic rate, and protein use, which in turn can negatively affect health and physical performance (50). Survey data indicate that a large number of North Americans have zinc intakes below recommended levels (74,75,79). Athletes, particularly women, are also at risk for zinc deficiency (79). The affect of low zinc intakes on zinc status is difficult to measure because clear assessment criteria have not been established and plasma zinc concentrations may not reflect changes in whole body zinc status (47,79). Decreases in cardiorespiratory function, muscle strength, and endurance have been noted with poor zinc status (47). The Tolerable Upper Intake Level for zinc is 40 mg (74). Athletes should be cautioned against single dose zinc supplements because they often exceed this amount and unnecessary zinc supplementation may lead to low high-density lipoprotein cholesterol and nutrient imbalances by interfering with absorption of other nutrients such as iron and copper (47). Furthermore, the benefits of zinc supplementation to physical performance have not been established.

Magnesium. Magnesium plays a variety of roles in cellular metabolism (eg, glycolysis, fat, and protein metabolism), and regulates membrane stability and neuromuscular, cardiovascular, immune, and hormonal functions (47,55). Magnesium deficiency impairs endurance performance by increasing oxygen requirements to complete submaximal exercise. Athletes in weight-class and body conscious sports such as wrestling, ballet, gymnastics, as well as tennis, have been reported to consume inadequate dietary magnesium. Athletes should be educated about good food sources of magnesium. In athletes with low magnesium status, supplementation might be beneficial (47).

Sodium, Chloride, and Potassium

Sodium is a critical electrolyte, particularly for athletes with high sweat losses (80-83). Many endurance athletes will require much more than the Tolerable Upper Intake Level for sodium (2.3 g/day) and chloride (3.6 g/day). Sports drinks containing sodium (0.5 to 0.7 g/L) and potassium (0.8 to 2.0 g/L), as well as carbohydrate, are recommended for athletes especially in endurance events (>2 hours) (50,80,82,83).

Potassium is important for fluid and electrolyte balance, nerve transmission, and active transport mechanisms. During intense exercise, plasma potassium concentrations tend to decline to a lesser degree than sodium. A diet rich in a variety of fresh vegetables, fruits, nuts and seeds, dairy foods, lean meats, and whole grains is usually considered adequate for maintaining normal potassium status among athletes (32,83).

HYDRATION

Being well hydrated is an important consideration for optimal exercise performance. Because dehydration increases the risk of potentially life-threatening heat injury such as heat stroke, athletes should strive for euhydration before, during, and after exercise. Dehydration (loss of >2% body weight) can compromise aerobic exercise performance, particularly in hot weather, and may impair mental/cognitive performance (83).

The American College of Sports Medicine's Position Stand on Exercise and Fluid Replacement (83) provides a comprehensive review of the research and recommendations for maintaining hydration before, during, and after exercise. In addition, the American College of Sports Medicine has published position stands specific to special environmental conditions (84,85). The major points from these position stands are the basis for the following recommendations.

Fluid and Electrolyte Recommendations

Before Exercise. At least 4 hours before exercise, individuals should drink about 5 to 7 mL/kg body weight (~2 to 3 mL/lb) of water or a sport beverage. This would allow enough time to optimize hydration status and for excretion of any excess fluid as urine. Hyperhydration with fluids that expand the extra- and intracellular spaces (eg, water and glycerol solutions) will greatly increase the risk of having to void during competition (83) and provides no clear physiologic or performance advantage over euhydration. This practice should be discouraged (83).

During Exercise. Athletes dissipate heat produced during physical activity by radiation, conduction, convection, and by vaporization of water. In hot, dry environments, evaporation accounts for more than 80% of metabolic heat loss. Sweat rates for any given activity will vary according to ambient temperature, humidity, body weight, genetics, heat acclimatization state, and metabolic efficiency. Depending on the sport and condition, sweat rates can range from as little as 0.3 to as much as 2.4 liters per hour (83). In addition to water, sweat also contains substantial but variable amounts of sodium. The average concentration of sodium in sweat approximates 1 g/L (50 mmol/L) (although concentrations vary widely). There are modest amounts of potassium and small amounts of minerals such as magnesium and chloride lost in sweat.

The intent of drinking during exercise is to avert a water deficit in excess of 2% of body weight. The amount and rate of fluid replacement is dependent on an individual athlete's sweat rate, exercise duration, and opportunities to drink (83). Readers are referred to the American College of Sports Medicine position stand for specific recommendations related to body size, sweat rates, types of work, and encouraged to individualize hydration protocols when possible (83). Routine measurement of pre- and postexercise body weights will assist practitioners in determining sweat rates and customizing fluid replacement programs for individual athletes (83).

Consumption of beverages containing electrolytes and carbohydrates can help sustain fluid and electrolyte balance and endurance exercise performance (83). The type, intensity, and duration of exercise and environmental conditions will alter the need for fluids and electrolytes. Fluids containing sodium and potassium help replace sweat electrolyte losses, whereas sodium stimulates thirst and fluid retention, and carbohydrates provide energy. Beverages containing 6% to 8% carbohydrate are recommended for exercise events lasting longer than 1 hour (83).

Fluid balance during exercise is not always possible because maximal sweat rates exceed maximal gastric emptying rates that in turn limit fluid absorption and most often rates of fluid ingestion by athletes during exercise fall short of amounts that can be emptied from the stomach and absorbed by the gut. Gastric emptying is maximized when the amount of fluid in the stomach is high and reduced with hypertonic fluids or when carbohydrate concentration is >8%.

Disturbances of fluid and electrolyte balance that can occur in athletes include dehydration, hypohydration, and hyponatremia (83). Exercise-induced dehydration develops because fluid losses that exceed fluid intake. Although some individuals begin exercise euhydrated and dehydrate over an extended duration, athletes in some sports might start training or competition in a dehydrated state because the interval between exercise sessions is inadequate for full rehydration (82). Another factor that may predispose an athlete to dehydration is making weight as a prerequisite for a specific sport or event. Hypohydration, a practice of some athletes competing in weight class sports (eg, wrestling, boxing, lightweight crew, and martial arts), can occur when athletes dehydrate themselves before beginning a competitive event. Hypohydration can develop by fluid restriction, certain exercise practices, diuretic use, or sauna exposure before an event. In addition, fluid deficits may span workouts for athletes who participate in multiple or prolonged daily sessions of exercise in the heat (84).

Hyponatremia (serum sodium concentration <130 mEq/L [<130 mmol/L]) can result from prolonged, heavy sweating with failure to replace sodium, or excessive water intake. Hyponatremia is more likely to develop in novice marathoners who are not lean, run slowly, sweat less or consume excess water before, during, or after an event (83).

Skeletal muscle cramps are associated with dehydration, electrolyte deficits, and muscle fatigue. Non–heat acclimatized American football players commonly experience dehydration and muscle cramping particularly during formal preseason practice sessions in late summer. Athletes participating in tennis matches, long cycling races, late-season triathlons, soccer, and beach volleyball are also susceptible to dehydration and muscle cramping. Muscle cramps also occur in winter-sport athletes such as cross-country skiers and ice-hockey players. Muscle cramps are more common in profuse sweaters who experience large sweat sodium losses (83).

After Exercise. Because many athletes do not consume enough fluids during exercise to balance fluid losses, they complete their exercise session dehydrated to some extent. Given adequate time, intake of normal meals and beverages will restore hydration status by replacing fluids and electrolytes lost during exercise. Rapid and complete recovery from excessive dehydration can be accomplished by drinking at least 16 to 24 oz (450 to 675 mL) of fluid for every pound (0.5 kg) of body weight lost during exercise. Consuming rehydration beverages and salty foods at meals/snacks will help replace fluid and electrolyte losses (83).

Special Environmental Conditions

Hot and Humid Environments. The risk for dehydration and heat injury increases dramatically in hot, humid environments (84). When the ambient temperature exceeds body temperature, heat cannot be dissipated by radiation. Moreover, the potential to dissipate heat by evaporation of sweat is substantially reduced when the relative humidity is high. There is a very high risk of heat illness when temperature and humidity are both high. If competitive events occur under these conditions, it is necessary to take every precaution to assure that athletes are well hydrated, have ample access to fluids, and are monitored for heat-related illness.

Cold Environments. It is possible for dehydration to occur in cool or cold weather (85). Factors contributing to dehydration in cold environments include respiratory fluid losses, as well as sweat losses that occur when insulated clothing is worn during intense exercise. Dehydration can also occur because of low rates of fluid ingestion. If an athlete is chilled and available fluids are cold, the incentive to drink may be reduced. Finally, removal of multiple layers of clothing to urinate may be inconvenient and difficult for some athletes, especially women, and they may voluntarily limit fluid intake (86).

Altitude. Fluid losses beyond those associated with any exercise performed may occur at altitudes >2,500 m (8,200 ft) consequent to mandatory diuresis and high respiratory water losses, accompanied by decreased appetite. Respiratory water losses may be as high as 1,900 mL (1.9 L) per day in men and 850 mL (0.85 L) per day in women (87,88). Total fluid intake at high altitude approaches 3 to 4 L per day to promote optimal kidney function and maintain urine output of ~1.4 L in adults (87).

THE TRAINING DIET

The fundamental differences between an athlete's diet and that of the general population are that athletes require additional fluid to cover sweat losses and additional energy to fuel physical activity. As discussed earlier, it is appropriate for much of the additional energy to be supplied as carbohydrate. The proportional increase in energy requirements appears to exceed the proportional increase in needs for most other nutrients. Accordingly, as energy requirements increase, athletes should first aim to consume the maximum number of servings appropriate for their needs from carbohydrate-based food groups (ie, bread, cereals and grains, legumes, milk/alternatives, vegetables, and fruits). Energy needs for many athletes will exceed the amount of energy (kilocalories per day) in the upper range of servings for these food groups. Conversely, athletes who are small and/or have lower energy needs will need to pay greater attention to making nutrient-dense food choices to obtain adequate carbohydrate, protein, essential fats, and micronutrients.

With regard to the timing of meals and snacks, common sense dictates that food and fluid intake around workouts be determined on an individual basis with consideration for an athlete's gastrointestinal characteristics as well as the duration and intensity of the workout. For example, an athlete might tolerate a snack consisting of milk and a sandwich 1 hour before a low-intensity workout, but would be uncomfortable if the same meal was consumed before a very hard effort. Athletes in heavy training or doing multiple daily workouts may need to eat more than three meals and three snacks per day and should consider every possible eating occasion. These athletes should consider eating in close proximity to the end of a workout, having more than one afternoon snack, or eating a substantial snack before bed.

Conclusion Statement. Twenty-three studies investigating consumption of a range of macronutrient composition during the training period on athletic performance were evaluated. Nine studies have reported that the consumption of a high carbohydrate diet (>60% of energy) during the training period and the week before competition results in improved muscle glycogen concentrations and/or significant improvements in athletic performance. Two studies reported no additional performance benefits when consuming levels above 6 g carbohydrate/kg body weight. Two studies report sex differences; women may have less ability to increase muscle glycogen concentrations through increased carbohydrate consumption, especially when energy intake is insufficient. One study based on the consumption of a high-fat diet (>65% of energy) for 10 days followed by a high-carbohydrate diet (>65% of energy) for 3 days reported a significant improvement in athletic performance. Nine studies report no significant effects of macronutrient composition on athletic performance during the training period and week prior to competition. **Evidence Grade II=Fair** (www.adaevidencelibrary.com/conclusion.cfm?conclusion_statement_id=250447).

Pre-Exercise Meal

Eating before exercise, as opposed to exercising in the fasting state, has been shown to improve performance (89,90). The meal or snack consumed before competition or an intense workout should prepare athletes for the upcoming activity, and leave the individual neither hungry nor with undigested food in the stomach. Accordingly, the following general guidelines for meals and snacks should be used: sufficient fluid should be ingested to maintain hydration, foods should be relatively low in fat and fiber to facilitate gastric emptying and minimize gastrointestinal distress, high in carbohydrate to maintain blood glucose and maximize glycogen stores, moderate in protein, and familiar to the athlete.

The size and timing of the pre-exercise meal are interrelated. Because most athletes do not like to compete on a full stomach, smaller meals should be consumed in closer proximity to the event to allow for gastric emptying, whereas larger meals can be consumed when more time is available before exercise or competition. Amounts of carbohydrate shown to enhance performance have ranged from approximately 200 to 300 g carbohydrate for meals consumed 3 to 4 hours before exercise. Studies report either no effect or beneficial effects of pre-event feeding on performance (91-98). Data are equivocal concerning whether the glycemic index of carbohydrate in the pre-exercise meal affects performance (92,99-102).

Although the above guidelines are sound and effective, the athlete's individual needs must be emphasized. Some athletes consume and enjoy a substantial meal (eg, pancakes, juice, and scrambled eggs) 2 to 4 hours before exercise or competition; however, others may suffer severe gastrointestinal distress following such a meal and need to rely on liquid meals. Athletes should always ensure that they know what works best for themselves by experimenting with new foods and beverages during practice sessions and planning ahead to ensure they will have access to these foods at the appropriate time.

Conclusion Statement. Nineteen studies investigating the consumption of a range of macronutrient composition during the 24 hours before competition on athletic performance were evaluated. Of eight studies, six reported no significant effect of meal consumption 90 minutes to 4 hours before trials on athletic performance. Six studies that focused on the consumption of food or beverage within the hour before competition reported no significant effects on athletic performance, despite hyperglycemia, hyperinsulinemia, increased carbohydrate oxidation, and reduced free fatty acid availability. Variations in research methodology on glycemic index of meals consumed prior to competition have led to inconclusive findings. **Evidence Grade II=Fair** (www.adaevidencelibrary.com/conclusion.cfm?conclusion_statement_id=250452).

During Exercise

Current research supports the benefit of carbohydrate consumption in amounts typically provided in sport drinks (6% to 8%) to endurance performance in events lasting 1 hour or less (103-105), especially in athletes who exercise in the morning after an overnight fast when liver glycogen levels are decreased. Providing exogenous carbohydrate during exercise helps maintain blood glucose levels and improve performance (106).

For longer events, consuming 0.7 g carbohydrate/kg body weight per hour (approximately 30 to 60 g per hour) has been shown unequivocally to extend endurance performance (107,108). Consuming carbohydrates during exercise is even more important in situations when athletes have not carbohydrate-loaded, not consumed preexercise meals, or restricted energy intake for weight loss. Carbohydrate intake should begin shortly after the onset of activity; consuming a given amount of carbohydrate as a bolus after 2 hours of exercise is not as effective as consuming the same amount at 15 to 20 minute intervals throughout the 2 hours of activity (109). The carbohydrate consumed should yield primarily glucose; fructose alone is not as effective and may cause diarrhea, although mixtures of glucose and fructose, other simple sugars and maltodextrins, appear effective (107). If the same total amount of carbohydrate and fluid is ingested, the form of carbohydrate does not seem to matter. Some athletes may prefer to use a sport drink whereas others may prefer to consume a carbohydrate snack or sports gel and consume water. As described elsewhere in this document, adequate fluid intake is also essential for maintaining endurance performance.

Conclusion Statement. Thirty-six studies investigating the consumption of a range of macronutrient composition during competition on athletic performance were evaluated. Seven studies based on carbohydrate consumption during exercise lasting less than 60 minutes show conflicting results on athletic performance. However, of 17 studies based on carbohydrate consumption during exercise lasting greater than 60 minutes, five reported improved metabolic response, and seven of 12 studies reported improvements in athletic performance. Evidence is inconclusive regarding the addition of protein to carbohydrate during exercise on athletic performance. Seven studies based on consumption of preexercise meals in addition to carbohydrate consumption during exercise suggest enhanced athletic performance. **Evidence Grade II=Fair** (www.adaevidencelibrary.com/conclusion.cfm?conclusion_statement_id=250453).

Recovery

The timing and composition of the post competition or postexercise meal or snack depend on the length and intensity of the exercise session (eg, whether glycogen depletion occurred), and when the next intense workout will occur. For example, most athletes will finish a marathon with depleted glycogen stores, whereas glycogen depletion would be less marked following a 90-minute training run. Because athletes competing in a marathon are not likely to perform another race or hard workout the same day, the timing and composition of the postexercise meal is less critical for these athletes. Conversely, a triathlete participating in a 90-minute run in the morning and a 3-hour cycling workout in the afternoon needs to maximize recovery between training sessions. The post workout meal assumes considerable importance in meeting this goal.

Timing of post-exercise carbohydrate intake affects glycogen synthesis over the short term (110). Consumption of carbohydrates within 30 minutes after exercise (1.0 to 1.5 g carbohydrate/kg at 2-hour intervals up to 6 hours is often recommended) results in higher glycogen levels post exercise than when ingestion is delayed for 2 hours (111). It is unnecessary for athletes who rest one or more days between intense training sessions to practice nutrient timing with regard to glycogen replenishment provided sufficient carbohydrates are consumed during the 24-hour period subsequent to the exercise bout (112). Nevertheless, consuming a meal or snack in close proximity to the end of exercise may be important for athletes to meet daily carbohydrate and energy goals.

The type of carbohydrate consumed also affects post-exercise glycogen synthesis. When comparing simple sugars, glucose and sucrose appear equally effective when consumed at a rate of 1.0 to 1.5 g/kg body weight for 2 hours; fructose alone is less effective (113). With regard to whole foods, consumption of carbohydrate with a high glycemic index results in higher muscle glycogen levels 24 hours after glycogen-depleting exercise as compared with the same amount of carbohydrates provided as foods with a low glycemic index (114). Application of these findings must be considered in conjunction with the athlete's overall diet. When isocaloric amounts of carbohydrates or carbohydrates plus protein and fat are provided following endurance (115) or resistance exercise (116), glycogen synthesis rates are similar. Including protein in a postexercise meal may provide needed amino acids for muscle protein repair and promote a more anabolic hormonal profile (33).

Conclusion Statement. Twenty-five studies investigating the consumption of a range of macronutrient composition during the recovery period were evaluated. Nine studies report that consumption of diets higher in carbohydrate (>65% carbohydrate or 0.8 to 1.0 g carbohydrate/kg body weight/hour) during the recovery period increase plasma glucose and insulin concentrations and increase muscle glycogen resynthesis. Provided that carbohydrate intake is sufficient, four studies show no significant benefit of additional protein intake and two studies show no significant effect of meal timing on muscle glycogen resynthesis during the recovery period. Studies focusing on carbohydrate consumption during recovery periods of 4 hours or more suggest improvements in athletic performance. **Evidence Grade II=Fair** (www.adaevidencelibrary.com/conclusion.cfm?conclusion_statement_id=250451).

DIETARY SUPPLEMENTS AND ERGOGENIC AIDS

The overwhelming number and increased availability of sports supplements presents an ongoing challenge for the practitioner and the athlete to keep up-to-date about the validity of both the claims and scientific evidence. Although dietary supplements, as well nutritional ergogenic aids—nutritional products that enhance performance—are highly prevalent, the fact remains that very few improve performance (117-119) and some may cause concern.

In the United States, the Dietary Supplements and Health Education Act of 1994 allows supplement manufacturers to make health claims regarding the effect of products on body structure or function, but not therapeutic claims to "diagnose, mitigate, treat, cure, or prevent" a specific disease or medical condition (117,120). As long as a special supplement label indicates the active ingredients and the entire ingredients list is provided, claims for enhanced performance can be made, valid or not. The Act, however, made the US Food and Drug Administration responsible for evaluating and enforcing safety. In 2003, the Food and Drug Administration Task Force on Consumer Health Information for Better Nutrition proposed a new system for evaluating health claims that uses an evidence-based model and is intended to help consumers determine effectiveness of ergogenic aids and dietary supplements more reliably (117). Although all manufacturers are required by the Food and Drug Administration to analyze the identity, purity, and strength of all of their products' ingredients, they are not required to demonstrate the safety and efficacy of their products.

Canada regulates supplements as medicine or as natural health products (NHPs). Products regulated in Canada as NHPs must comply with NHP Regulations (as of 2003) and manufacturers are allowed to make a full range of claims (eg, structure/function, risk reduction, treatment, and prevention) as supported by scientific evidence (117). In Canada, sports supplements such as sport drinks, protein powders, energy bars, and meal replacement products/beverages are regulated by Health Canada's Canadian Food Inspection Agency, whereas energy drinks, vitamin/mineral and herbal supplements, vitamin-enhanced water, and amino acid supplements fall under the NHP Regulations. Anabolic steroids are considered drugs and are tightly regulated under the Controlled Drugs & Substances Act.

Sports dietitians should consider the following factors in evaluating nutrition-related ergogenic aids: validity of the claims relative to the science of nutrition and exercise, quality of the supportive evidence provided (double-blinded, placebo-controlled scientific studies vs testimonials), and health and legal consequences of the claim (86,121). The safety of ergogenic aids remains in question. Possible contamination of dietary supplements and ergogenic aids with banned or nonpermissable substances remains an issue of concern. Therefore, sports dietitians and athletes must proceed with caution when considering the use of these types of products. Ultimately, the individual athlete is responsible for the products ingested and any subsequent consequences. Dietary supplements or ergogenic aids will never substitute for genetic make-up, years of training, and optimum nutrition.

Both national (National Collegiate Athletic Association [www.ncaa.org]; United States Anti-Doping Agency [www.usantidoping.org]) and international (World Anti-Doping Agency [www.wada-ama.org]) sports organizations limit the use of certain ergogenic aids and require random urine testing of athletes to ensure that certain products are not consumed. In Canada, the Canadian Centre for Ethics in Sport (www.cces.ca) is the organization that checks for banned substances.

The ethical use of performance-enhancing substances is a personal choice and remains controversial (117). Therefore, it is important that the qualified sports nutrition professional keep an open mind when working with elite athletes to effectively assess, recommend, educate, and monitor athletes who contemplate using or actively take dietary supplements and/or ergogenic aids (117). Credible and responsible information regarding the use of these products should be made available by qualified health professionals such as a Board Certified Specialist in Sports Dietetics who carefully evaluate the risk: benefit ratio, including a complete dietary assessment.

It is beyond the scope of this paper to address the multitude of ergogenic aids used by athletes in North America. From a practical perspective most ergogenic aids can be classified into one of four categories: those that perform as claimed; those that may perform as claimed but for which there is insufficient evidence of efficacy at this time; those that do not perform as claimed; and those that are dangerous, banned, or illegal, and therefore should not be used (122).

Ergogenic Aids that Perform as Claimed

Creatine. Creatine is currently the most widely used ergogenic aid among athletes wanting to build muscle and enhance recovery (118,123-125). Creatine has been shown to be effective in repeated short bursts of high intensity activity in sports that derive energy primarily from the ATP-creatine phosphate energy system such as sprinting and weight lifting, but not for endurance sports such as distance running (32,117,126-128). Most of the research on creatine has been conducted in a laboratory setting with male athletes.

The most common side effects of creatine supplementation are weight (fluid) gain, cramping, nausea, and diarrhea (32,117,129). Although widely debated, creatine is generally considered safe for healthy adults, despite anecdotal reports of dehydration, muscle strains/tears, and kidney damage (130-132). Although the effects of long-term use of creatine remain unknown, studies to date do not show any adverse effects in healthy adults from creatine supplementation (133). Nevertheless, health care professionals should carefully screen athletes using creatine for any risk of liver or kidney dysfunction or in rare instances, anterior compartment syndrome.

Caffeine. Caffeine's potential ergogenic effects may be more closely related to its role as a central nervous system stimulant and the associated decreased perception of effort as opposed to its role in mobilizing of free fatty acids and sparing of muscle glycogen (117,134). In 2004, World Anti-Doping Agency moved caffeine from the restricted list to its Monitoring Programme. However, caffeine is still a restricted substance by the National Collegiate Athletic Association, where a positive doping test would be a caffeine level >15 μg/mL urine. New evidence shows that caffeine when used in moderation does not cause dehydration or electrolyte imbalance (135-138). However, when rapid hydration is necessary, athletes should rely on noncaffeinated and nonalcoholic beverages.

The use of high-energy drinks containing caffeine can be ergolytic and potentially dangerous when used in excess or in combination with stimulants or alcohol or other unregulated herbals and should be discouraged (32,117,139-141). Side effects of caffeine are anxiety, jitteriness, rapid heartbeat, gastrointestinal distress, and insomnia and could be ergolytic for novice users (134,142). There is little evidence to promote use of caffeine alone as a weight loss aid (118).

Sports drinks, Gels, and Bars. Sports drinks, gels, and bars are commonly used as convenient dietary supplements or ergogenic aids for busy athletes and active people. It is important that qualified nutrition professionals educate consumers about label reading, product composition and appropriate use of these products (before, during, and after training and competition).

Sodium Bicarbonate. Sodium bicarbonate may be an effective ergogenic aid as a blood buffer (role in acid-base balance and prevention of fatigue) but its use is not without unpleasant side effects such as diarrhea (117,143).

Protein and Amino Acid Supplements. Current evidence indicates that protein and amino acid supplements are no more or no less effective than food when energy is adequate for gaining lean body mass (30,31,117) Although widely used, protein powders and amino acid supplements are a potential source for illegal substances such as nandrolone, which may not be listed on the ingredient label (144,145).

Ergogenic Aids that May Perform as Claimed, but for which there Is Insufficient Evidence

The ergogenic aids that have claims as health and performance enhancers include: glutamine, beta hydroxymethylbutyrate, colostrum, and ribose (117). Preliminary studies concerning these ergogenic aids are inconclusive as performance enhancers. These substances are not banned from use by athletes (www.wada-ama.org/en/prohibitedlist.ch2).

Ergogenic Aids that Do Not Perform as Claimed

The majority of ergogenic aids currently on the market are in this category (122). These include: amino acids, bee pollen, branched chain amino acids, carnitine, chromium picolinate, cordyceps, Coenzyme Q10, conjugated linoleic acid, Cytochrome C, dihydroxyacetone, gamma oryzanol, ginseng, inosine, medium chain triglycerides, pyruvate, oxygenated water, and vanadium. This list is by no means exhaustive and it is likely that other substances would be best placed in this category. Similarly, it is possible for any of these compounds to eventually move from this to another category subsequent to appropriate scientific inquiry and evaluation. To date none of these products has been shown to enhance performance and many have had adverse effects (122).

Ergogenic Aids that Are Dangerous, Banned, or Illegal

The ergogenic aids in this category should not be used and are banned by the World Anti-Doping Agency. Examples are androstenedione, dehydroepiandrosterone, 19-norandrostenedione, 19-norandrostenediol, and other anabolic, androgenic steroids, Tribulis terrestris, ephedra, strychnine, and human growth hormone. Because this is an evolving field, sports dietitians need to consistently consider the status of various nutritional ergogenic aids.

VEGETARIAN ATHLETES

The Position Statement of the American Dietetic Association and Dietitians of Canada on vegetarian diets (2003) provides appropriate dietary guidance for vegetarian athletes. This position provides additional considerations for vegetarians who participate in exercise. Well-planned vegetarian diets appear to effectively support parameters that influence athletic performance, although studies on this population are limited (31,146). Plant-based, high-fiber diets may reduce energy availability. Monitoring body weight and body composition is the preferred means of determining if energy needs are met. Some individuals, especially women, may switch to vegetarianism as a means of avoiding red meat and/or restricting energy intake to attain a lean body composition favored in some sports. Occasionally this may be a red flag for disordered eating and increase the risk for the female athlete triad (72,73). Because of this association, coaches, trainers, and other health professionals should be alert when an athlete becomes a vegetarian and should ensure that appropriate weight is maintained.

Although most vegetarian athletes meet or exceed recommendations for total protein intake, their diets often provide less protein than those of nonvegetarians (31). Thus, some individuals may need more protein to meet training and competition needs (31). Protein quality of plant-based diets should be sufficient provided a variety of foods is consumed that supply adequate energy (31). Protein quality is a potential concern for individuals who avoid all animal proteins such as milk and meat (eg, vegans). Their diets may be limited in lysine, threonine, tryptophan, or methionine (39).

Because plant proteins are less well digested than animal proteins, an increase in intake of about 10% protein is advised (15). Therefore, protein recommendations for vegetarian athletes approximate 1.3 to 1.8 g/kg/day (52). Vegetarians with relatively low energy intakes should choose foods wisely to ensure protein intakes are consistent with these recommendations.

Vegetarian athletes may be at risk for low intakes of energy; fat; vitamins B-12, riboflavin, and D; calcium; iron; and zinc, which are readily available from animal proteins. Iron is of particular concern because of the low bioavailability of non-heme plant sources. Iron stores of vegetarians are generally lower than omnivores (52). Vegetarian athletes, especially women, may be at greater risk for developing iron deficiency or anemia. Routine monitoring of iron status is recommended for vegetarian athletes, especially during periods of rapid growth (eg, adolescence and pregnancy). Very-low-fat diets or avoidance of all animal protein may lead to a deficiency of essential fatty acids. Sports dietitians should educate novice vegetarian athletes on resources for menu planning, cooking, and shopping—especially high-quality plant protein combinations and acceptable animal sources (eg, dairy and eggs) as well as foods rich in or fortified with key nutrients (eg, vitamins D, B-12, and riboflavin; iron; calcium; and zinc) (52).

ROLES AND RESPONSIBILITIES OF SPORTS DIETITIANS

As nutrition information advances in quantity and complexity, athletes and active individuals are presented with a myriad of choices and decisions about appropriate and effective nutrition for activity and performance. Increasingly, athletes and active individuals seek professionals to guide them in making optimal food and fluid choices. Although many athletes and active individuals view winning or placing in an event to be the ultimate evidence of the effectiveness of their dietary regimens, sports dietitians should address the combined goals of health and fitness, enhanced capacity to train, and optimal athletic performance. Therefore, sports dietitians should be competent in the following areas:

Roles

- Conduct comprehensive nutrition assessment and consultation;
- educate in food selection, purchasing, and preparation;

- provide medical nutrition therapy in private practice, health care, and sports settings;
- identify and treat nutritional issues that influence health and performance;
- address energy balance and weight management issues;
- address nutritional challenges to performance (eg, gastrointestinal disturbances, iron depletion, eating disorders, female athlete triad, food allergies, and supplement use);
- track and document measurable outcomes of nutrition services;
- promote wound and injury healing;
- oversee menu planning and design, including pre- and postevent and travel;
- develop and oversee nutrition polices and procedures; and
- evaluate the scientific literature and provide evidence-based assessment and application.

Responsibilities

- Apply sports nutrition science to fueling fitness and performance;
- develop personalized nutrition and hydration strategies;
- advise on dietary supplements, ergogenic aids, meal and fluid replacement products, sports drinks, bars, and gels;
- evaluate dietary supplements and sports foods for legality, safety, and efficacy;
- provide nutrition strategies to delay fatigue during exercise and speed recovery from training;
- help enhance athletic training capacity and performance;
- participate in identifying and treating disordered eating patterns;
- provide nutrition strategies to reduce risk of illness/injury and facilitate recovery;
- promote career longevity for collegiate and professional athlete and all active individuals;
- recruit and retain clients and athletes in practice;
- provide sports nutrition as member of multidisciplinary/medical/health care teams;
- provide reimbursable services (diabetes medical nutrition therapy);
- design and conduct sports team education;
- serve as a mentor for developing sports dietetics professionals; and
- maintain credential(s) by actively engaging in profession-specific continuing education activities.

The aforementioned responsibilities should be routine expectations of sporting and sports medicine organizations that employ qualified sports dietitians and of clients and athletes seeking valid sports nutrition information and advice.

In 2005, the Commission on Dietetic Registration (the credentialing agency of the American Dietetic Association) created a specialty credential for food and nutrition professionals who specialize in sports dietetic practice. The Board Certified Specialist in Sports Dietetics credential is designed as the premier professional sports nutrition credential in the United States. Specialists in sports dietetics provide safe, effective, evidence-based nutrition assessment, guidance, and counseling for health and performance for athletes, sport organizations, and physically active individuals and groups. The credential requires current registered dietitian status, maintenance of registered dietitian status for a minimum of 2 years, and documentation of 1,500 sports specialty practice hours as a registered dietitian within the past 5 years. For more information, readers are referred to www.cdrnet.org/whatsnew/Sports.htm.

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References

1. American Dietetic Association. Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. *J Am Diet Assoc*. 2000;100: 1543-1556.
2. Mougios V. *Exercise Biochemistry*. Champaign, IL: Human Kinetics; 2006.
3. Coyle E, Jeukendrup A, Wagenmakers A, Saris W. Fatty acid oxidation is directly regulated by carbohydrate metabolism during exercise. *Am J Physiol*. 1997;273:E268-275.
4. Turcotte L. Role of fats in exercise. Types and quality. *Clin Sports Med*. 1999;18:485-498.
5. Donahoo W, Levine J, Melanson E. Variability in energy expenditure and its components. *Curr Opin Clin Nutr Metab Care*. 2004;7:599-605.
6. Thompson JL, Manore MM, Skinner JS, Ravussin E, Spraul M. Daily energy expenditure in male endurance athletes with differing energy intakes. *Med Sci Sports Exerc*. 1995;27:347-354.
7. Beals K, Houtkooper L. Disordered eating in athletes. In: Burke L, Deakin V, eds. *Clinical Sports Nutrition*. Sydney, Australia: McGraw-Hill 2006;201-226.
8. Gabel KA. Special nutritional concerns for the female athlete. *Curr Sports Med Rep*. 2006;5:187-191.
9. Sundgot-Borgen J, Torstveit MK. Prevalence of eating disorders in elite athletes is higher than in the general population. *Clin J Sport Med*. 2004;14:25-32.
10. Beals K, Manore M. Nutritional considerations for the female athlete. In:*Advances in Sports and Exercise Science Series*. Philadelphia, PA: Elsevier; 2007:187-206.
11. Burke LM, Loucks AB, Broad N. Energy and carbohydrate for training and recovery. *J Sports Sci*. 2006;24:675-685.
12. Deuster PA, Kyle SB, Moser PB, Vigersky RA, Singh A, Schoomaker EB. Nutritional intakes and status of highly trained amenorrheic and eumenorrheic women runners. *Fertil Steril*. 1986;46:636-643.
13. Kopp-Woodroffe SA, Manore MM, Dueck CA, Skinner JS, Matt KS. Energy and nutrient status of amenorrheic athletes participating in a diet and exercise training intervention program. *Int J Sport Nutr*. 1999;9:70-88.
14. Loucks AB, Verdun M, Heath EM. Low energy availability, not stress of exercise, alters LH pulsatility in exercising women. *J Appl Physiol*. 1998;84:37-46.
15. Otten J, Hellwig J, Meyers L, eds. *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements*. Washington, DC: National Academies Press; 2006.
16. Nutrition and Your Health: Dietary Guidelines for Americans, 2005. Section 3: Discretionary calories. http://www.health.gov/dietaryguidelines/dga2005/report/HTML/D3_Disccalories.htm. Accessed January 14, 2009.
17. Institute of Medicine, Food and Nutrition Board. *Dietary Reference intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*. Washington, DC: National Academies Press; 2005.
18. Cunningham JJ. A reanalysis of the factors influencing basal metabolic rate in normal adults. *Am J Clin Nutr*. 1980;33:2372-2374.
19. Harris J, Benedict F. *A Biometric Study of Basal Metabolism in Man*. Philadelphia, PA: Lippincott; 1919.
20. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, O'Brien WL, Bassett DR Jr, Schmitz KH, Emplaincourt PO, Jacobs DR Jr, Leon AS. Compendium of physical activities: An update of activity codes and MET intensities. *Med Sci Sports Exerc*. 2000;32(suppl 9):S498-504.
21. Houtkooper L. Body composition. In: Manore M, Thompson J, eds. *Sport Nutrition for Health and Performance*. Champaign, IL: Human Kinetics; 2000:197-216.
22. Heymsfield S, Lohman T, Wang Z, Going S. *Human Body Composition*. 2nd ed. Champaign, IL: Human Kinetics; 2005.

23. Siri W. Gross composition of the body. In: Lawrence J, Cornelius A, eds. *Advances in Biological and Medical Physics*. New York, NY: Academic Press; 1956:239-280.
24. Brozek J. Body composition: Models and estimation equations. *Am J Phys Anthropol*. 1966;24:239-246.
25. Going S. Optimizing techniques for determining body composition. *Gatorade Sports Sci Exch*. 2006;19:101.
26. Marfell-Jones M, Olds T, Stewart A, Carter L. *International Standards for Anthropometric Assessment*. Potchefstroom, South Africa: International Society for the Advancement of Kinanthropometry; 2006.
27. Chumlea W, Sun S. Bioelectric impedance analysis. In: Heymsfield S, Lohman T, Wang Z, Going S, eds. *Human Body Composition*. Champaign, IL: Human Kinetics; 2005:79-88.
28. Eating well with Canada's food guide. Health Canada Web site. http://www.hc-sc.gc.ca/fn-an/food-guide-aliment/index-eng.php. Accessed June 20, 2008.
29. Dunford M, *Sports Nutrition: A Practice Manual for Professionals*. 4th ed. Chicago, IL: American Dietetic Association; 2006.
30. Phillips SM, Moore DR, Tang J. A critical examination of dietary protein requirements, benefits, and excesses in athletes. *Int J Sports Nutr Exer Metab*. 2007; 17(suppl):S58-S76.
31. Tipton KD, Witard OC. Protein requirements and recommendations for athletes: Relevance of ivory tower arguments for practical recommendations. *Clin Sports Med*. 2007;26:17-36.
32. Burke L, Deakin V, *Clinical Sports Nutrition*. Sydney, Australia: McGraw-Hill; 2006.
33. Rodriguez NR, Vislocky LM, Gaine PC. Dietary protein, endurance exercise, and human skeletal-muscle protein turnover. *Curr Opin Clin Nutr Metab Care*. 2007;10: 40-45.
34. Gaine PC, Pikosky MA, Martin WF, Bolster DR, Maresh CM, Rodriguez NR. Level of dietary protein impacts whole body protein turnover in trained males at rest. *Metabolism*. 2006;55:501-507.
35. Phillips SM, Atkinson SA, Tarnopolsky MA, MacDougall JD. Gender differences in leucine kinetics and nitrogen balance in endurance athletes. *J Appl Physiol*. 1993;75: 2134-2141.
36. Tarnopolsky LJ, MacDougall JD, Atkinson SA, Tarnopolsky MA, Sutton JR. Gender differences in substrate for endurance exercise. *J Appl Physiol*. 1990;68:302-308.
37. Biolo G, Maggi SP, Williams BD, Tipton KD, Wolfe RR. Increased rates of muscle protein turnover and amino acid transport after resistance exercise in humans. *Am J Physiol*. 1995;268:E514-520.
38. Tipton KD, Ferrando AA, Phillips SM, Doyle D Jr, Wolfe RR. Postexercise net protein synthesis in human muscle from orally administered amino acids. *Am J Physiol*. 1999;276:E628-634.
39. Tipton KD, Elliott TA, Cree MG, Aarsland AA, Sanford AP, Wolfe RR. Stimulation of net muscle protein synthesis by whey protein ingestion before and after exercise. *Am J Physiol Endocrinol Metab*. 2007;292: E71-76.
40. Hartman JW, Tang JE, Wilkinson SB, Tarnopolsky MA, Lawrence RL, Tipton KD, Rasmussen BB, Miller SL, Wolf SE, Owens-Stovall SK, Petrini BE, Wolfe RR. Timing of amino acid-carbohydrate ingestion alters anabolic response of muscle to resistance exercise. *Am J Physiol Endocrinol Metab*. 2001;281:E197-206.
41. Ivy JL, Res PT, Sprague RC, Widzer MO. Effect of a carbohydrate-protein supplement on endurance performance during exercise of varying intensity. *Int J Sport Nutr Exerc Metab*. 2003;13:382-395.
42. van Essen M, Gibala MJ. Failure of protein to improve time trial performance when added to a sports drink. *Med Sci Sports Exerc*. 2006;38:1476-1483.
43. Muoio DM, Leddy JJ, Horvath PJ, Awad AB, Pendergast DR. Effect of dietary fat on metabolic adjustments to maximal VO2 and endurance in runners. *Med Sci Sports Exerc*. 1994;26:81-88.
44. Lambert EV, Speechly DP, Dennis SC, Noakes TD. Enhanced endurance in trained cyclists during moderate intensity exercise following 2 weeks adaptation to a high fat diet. *Eur J Appl Physiol Occup Physiol*. 1994;69:287-293.
45. Jeukendrup A, Saris W. Fat as a fuel during exercise. In: Berning J, Steen S, eds. *Nutrition for Sport and Exercise*. Gaithersburg, MD: Aspen Publishers Inc; 1998:59-76.
46. Driskell J. Summary: Vitamins and trace elements in sports nutrition. In: Driskell J, Wolinsky I, eds. *Sports Nutrition: Vitamins and Trace Elements*. New York, NY: CRC/ Taylor & Francis; 2006:323-331.
47. Lukaski HC. Vitamin and mineral status: Effects on physical performance. *Nutrition*. 2004;20:632-644.
48. Woolf K, Manore MM. B-vitamins and exercise: Does exercise alter requirements? *Int J Sport Nutr Exerc Metab*. 2006;16:453-484.
49. Powers SK, DeRuisseau KC, Quindry J, Hamilton KL. Dietary antioxidants and exercise. *J Sports Sci*. 2004;22:81-94.
50. Volpe S. Vitamins, minerals, and exercise. In: Dunford M, ed. *Sports Nutrition: A Practice Manual for Professionals*. Chicago, IL: American Dietetic Association; 2006:61-63.
51. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Thiamine, Riboflavin, Niacin, Vitamin B6, Folate, Vitamin B12, Pantothenic acid, Biotin, and Choline*. Washington, DC: National Academies Press; 2000.
52. American Dietetic Association. Position of The American Dietetic Association and Dietitians of Canada: Vegetarian diets. *J Am Diet Assoc*. 2003;103:748-765.
53. Holick MF. Vitamin D deficiency. *N Engl J Med*. 2007;357:266-281.
54. Nakagawa K. Effect of vitamin D on the nervous system and the skeletal muscle. *Clin Calcium*. 2006;16:1182-1187.
55. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Calcium, Phosphorous, Magnesium, Vitamin D, and Fluoride*. Washington, DC: National Academies Press; 1997.
56. Meier C, Woitge HW, Witte K, Lemmer B, Seibel MJ. Supplementation with oral vitamin D3 and calcium during winter prevents seasonal bone loss: A randomized controlled open-label prospective trial. *J Bone Miner Res*. 2004;19:1221-1230.
57. Munger KL, Levin LI, Hollis BW, Howard NS, Ascherio A. Serum 25-hydroxyvitamin D levels and risk of multiple sclerosis. *JAMA*. 2006;296:2832-2838.
58. Whiting SJ, Barabash WA. Dietary Reference Intakes for the micronutrients: Considerations for physical activity. *Appl Physiol Nutr Metab*. 2006;31:80-85.
59. Bischoff-Ferrari HA, Dietrich T, Orav EJ, Hu FB, Zhang Y, Karlson EW, Dawson-Hughes B. Higher 25-hydroxyvitamin D concentrations are associated with better lower-extremity function in both active and inactive persons aged > or =60 y. *Am J Clin Nutr*. 2004;80:752-758.
60. Heaney RP, Davies KM, Chen TC, Holick MF, Barger-Lux MJ. Human serum 25-hydroxycholecalciferol response to extended oral dosing with cholecalciferol. *Am J Clin Nutr*. 2003;77:204-210.
61. Vieth R, Chan PC, MacFarlane GD. Efficacy and safety of vitamin D3 intake exceeding the lowest observed adverse effect level. *Am J Clin Nutr*. 2001;73:288-294.
62. Vieth R, Bischoff-Ferrari H, Boucher BJ, Dawson-Hughes B, Garland CF, Heaney RP, Holick MF, Hollis BW, Lamberg-Allardt C, McGrath JJ, Norman AW, Scragg R, Whiting SJ, Willett WC, Zittermann A. The urgent need to recommend an intake of vitamin D that is effective. *Am J Clin Nutr*. 2007;85:649-650.
63. Willis KS, Peterson NJ, Larson-Meyer DE. Should we be concerned about the vitamin D status of athletes? *Int J Sport Nutr Exerc Metab*. 2008;18:204-224.
64. Gleeson M, Nieman DC, Pedersen BK. Exercise, nutrition and immune function. *J Sports Sci*. 2004;22:115-125.
65. Watson TA, MacDonald-Wicks LK, Garg ML. Oxidative stress and antioxidants in athletes undertaking regular exercise training. *Int J Sport Nutr Exerc Metab*. 2005;15:131-146.
66. Mastaloudis A, Traber M. Vitamin E. In: Driskell J, Wolinsky I, eds. *Sports Nutrition: Vitamins and Trace Elements*. New York, NY: CRC/Taylor & Francis; 2006:183-200.
67. Takanami Y, Iwane H, Kawai Y, Shimomitsu T. Vitamin E supplementation and endurance exercise: Are there benefits? *Sports Med*. 2000;29:73-83.
68. Peake JM. Vitamin C: effects of exercise and requirements with training. *Int J Sport Nutr Exerc Metab*. 2003;13:125-151.
69. Keith R. Ascorbic acid. In: Driskell J, Wolinsky I, eds. *Sports Nutrition: Vitamins and Trace Elements*. New York, NY: CRC/ Taylor & Francis; 2006:29.
70. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids*. Washington, DC: National Academies Press; 2000.
71. Nickols-Richardson SM, Beiseigel JM, Gwazdauskas FC. Eating restraint is negatively associated with biomarkers of bone turnover but not measurements of bone mineral density in young women. *J Am Diet Assoc*. 2006;106:1095-1101.
72. International Olympic Committee Position Stand: Female athlete triad. IOC Medical Commission Working Group Women in Sport. International Olympic Committee Web site. http://multimedia.olympic.org/pdf/en_report_917.pdf. Accessed January 5, 2009.
73. Nattiv A, Loucks AB, Manore MM, Sanborn CF, Sundgot-Borgen J, Warren MP. American College of Sports Medicine posi-

tion stand. The female athlete triad. *Med Sci Sports Exerc*. 2007;39:1867-1882.
74. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc*. Washington, DC: National Academies Press; 2001.
75. Haymes E. Iron. In: Driskell J, Wolinsky I, eds. *Sports Nutrition; Vitamins and Trace Elements*. New York, NY: CRC/Taylor & Francis; 2006:203-216.
76. Brownlie T, Utermohlen V, Hinton PS, Haas JD. Tissue iron deficiency without anemia impairs adaptation in endurance capacity after aerobic training in previously untrained women. *Am J Clin Nutr*. 2004;79:437-443.
77. Benardot D. *Advanced Sports Nutrition*. Champagne, IL: Human Kinetics; 2006.
78. Cowell BS, Rosenbloom CA, Skinner R, Summers SH. Policies on screening female athletes for iron deficiency in NCAA division I-A institutions. *Int J Sport Nutr Exerc Metab*. 2003;13:277-285.
79. Micheletti A, Rossi R, Rufini S. Zinc status in athletes: Relation to diet and exercise. *Sports Med*. 2001;31:577-582.
80. Kenney W. Dietary water and sodium requirements for active adults. Gatorade Sports Science Institute Web site. http://www.gssiweb.com/Article_Detail.aspx?articleid=667. Accessed June 20, 2008.
81. Bergeron MF. Heat cramps: Fluid and electrolyte challenges during tennis in the heat. *J Sci Med Sport*. 2003;6:19-27.
82. Palmer MS, Spriet L. Sweat rate, salt loss, and fluid intake during an intense on-ice practice in elite Canadian male junior hockey players. *Appl Phys Nutr Metab*. 2008;33:267-271.
83. Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfeld NS. American College of Sports Medicine position stand. Exercise and fluid replacement. *Med Sci Sports Exerc*. 2007;39:377-390.
84. Armstrong LE, Casa DJ, Millard-Stafford M, Moran DS, Pyne SW, Roberts WO. American College of Sports Medicine position stand. Exertional heat illness during training and competition. *Med Sci Sports Exerc*. 2007;39:556-572.
85. Castellani JW, Young AJ, Ducharme MB, Giesbrecht GG, Glickman E, Sallis RE. American College of Sports Medicine position stand: Prevention of cold injuries during exercise. *Med Sci Sports Exerc*. 2006; 38:2012-2029.
86. Burke L. *Practical Sports Nutrition*. Champaign, IL: Human Kinetics; 2007.
87. Armstrong L. *Performing in Extreme Environments*. Champaign, IL: Human Kinetics; 2000.
88. Butterfield G. Maintenance of body weight at altitude: In search of 500 kcal/day. In: Marriott B, Carlson S, eds. *Nutritional Needs in Cold and High Altitude Environments*. Washington, DC: Committee on Military Nutrition Research; 1996:357-378.
89. Jentjens RL, Cale C, Gutch C, Jeukendrup AE. Effects of pre-exercise ingestion of differing amounts of carbohydrate on subsequent metabolism and cycling performance. *Eur J Appl Physiol*. 2003;88:444-452.
90. Moseley L, Lancaster GI, Jeukendrup AE. Effects of timing of pre-exercise ingestion of carbohydrate on subsequent metabolism and cycling performance. *Eur J Appl Physiol*. 2003;88:453-458.
91. Schabort EJ, Bosch AN, Weltan SM, Noakes TD. The effect of a preexercise meal on time to fatigue during prolonged cycling exercise. *Med Sci Sports Exerc*. 1999;31:464-471.
92. Wee SL, Williams C, Gray S, Horabin J. Influence of high and low glycemic index meals on endurance running capacity. *Med Sci Sports Exerc*. 1999;31:393-399.
93. Wee SL, Williams C, Tsintzas K, Boobis L. Ingestion of a high-glycemic index meal increases muscle glycogen storage at rest but augments its utilization during subsequent exercise. *J Appl Physiol*. 2005;99:707-714.
94. Okano G, Sato Y, Murata Y. Effect of elevated blood FFA levels on endurance performance after a single fat meal ingestion. *Med Sci Sports Exerc*. 1998;30:763-768.
95. Okano G, Sato Y, Takumi Y, Sugawara M. Effect of 4h preexercise high carbohydrate and high fat meal ingestion on endurance performance and metabolism. *Int J Sports Med*. 1996;17:530-534.
96. Cramp T, Broad E, Martin D, Meyer BJ. Effects of preexercise carbohydrate ingestion on mountain bike performance. *Med Sci Sports Exerc*. 2004;36:1602-1609.
97. Paul D, Jacobs KA, Geor RJ, Hinchcliff KW. No effect of pre-exercise meal on substrate metabolism and time trial performance during intense endurance exercise. *Int J Sport Nutr Exerc Metab*. 2003;13:489-503.
98. Whitley HA, Humphreys SM, Campbell IT, Keegan MA, Jayanetti TD, Sperry DA, MacLaren DP, Reilly T, Frayn KN. Metabolic and performance responses during endurance exercise after high-fat and high-carbohydrate meals. *J Appl Physiol*. 1998;85:418-424.
99. DeMarco HM, Sucher KP, Cisar CJ, Butterfield GE. Pre-exercise carbohydrate meals: Application of glycemic index. *Med Sci Sports Exerc*. 1999;31:164-170.
100. Kirwan JP, O'Gorman DJ, Cyr-Campbell D, Campbell WW, Yarasheski KE, Evans WJ. Effects of a moderate glycemic meal on exercise duration and substrate utilization. *Med Sci Sports Exerc*. 2001;33:1517-1523.
101. Febbraio MA, Stewart KL. CHO feeding before prolonged exercise: Effect of glycemic index on muscle glycogenolysis and exercise performance. *J Appl Physiol*. 1996; 81:1115-1120.
102. Febbraio MA, Keenan J, Angus DJ, Campbell SE, Garnham AP. Preexercise carbohydrate ingestion, glucose kinetics, and muscle glycogen use: Effect of the glycemic index. *J Appl Physiol*. 2000;89:1845-1851.
103. Sugiura K, Kobayashi K. Effect of carbohydrate ingestion on sprint performance following continuous and intermittent exercise. *Med Sci Sports Exerc*. 1998;30:1624-1630.
104. Jeukendrup A, Brouns F, Wagenmakers AJ, Saris WH. Carbohydrate-electrolyte feedings improve 1 h time trial cycling performance. *Int J Sports Med*. 1997;18:125-129.
105. Nicholas CW, Williams C, Lakomy HK, Phillips G, Nowitz A. Influence of ingesting a carbohydrate-electrolyte solution on endurance capacity during intermittent, high-intensity shuttle running. *J Sports Sci*. 1995;13:283-290.
106. Jeukendrup A. Carbohydrate supplementation during exercise: Does it help? How much is too much? Gatorade Sports Science Institute Web site. http://www.gssiweb.com/Article_Detail.aspx?articleid=757. Accessed June 20, 2008.
107. Coggan AR, Coyle EF. Carbohydrate ingestion during prolonged exercise: Effects on metabolism and performance. *Exerc Sport Sci Rev*. 1991;19:1-40.
108. Currell K, Jeukendrup AE. Superior endurance performance with ingestion of multiple transportable carbohydrates. *Med Sci Sports Exerc*. 2008;40:275-281.
109. McConell G, Kloot K, Hargreaves M. Effect of timing of carbohydrate ingestion on endurance exercise performance. *Med Sci Sports Exerc*. 1996;28:1300-1304.
110. Jentjens R, Jeukendrup A. Determinants of post-exercise glycogen synthesis during short-term recovery. *Sports Med*. 2003;33: 117-144.
111. Ivy JL, Katz AL, Cutler CL, Sherman WM, Coyle EF. Muscle glycogen synthesis after exercise: Effect of time of carbohydrate ingestion. *J Appl Physiol*. 1988;64:1480-1485.
112. Burke LM, Collier GR, Davis PG, Fricker PA, Sanigorski AJ, Hargreaves M. Muscle glycogen storage after prolonged exercise: Effect of the frequency of carbohydrate feedings. *Am J Clin Nutr*. 1996;64:115-119.
113. Blom PC, Hostmark AT, Vaage O, Kardel KR, Maehlum S. Effect of different post-exercise sugar diets on the rate of muscle glycogen synthesis. *Med Sci Sports Exerc*. 1987;19:491-496.
114. Burke LM, Collier GR, Hargreaves M. Muscle glycogen storage after prolonged exercise: Effect of the glycemic index of carbohydrate feedings. *J Appl Physiol*. 1993; 75:1019-1023.
115. Burke LM, Collier GR, Beasley SK, Davis PG, Fricker PA, Heeley P, Walder K, Hargreaves M. Effect of coingestion of fat and protein with carbohydrate feedings on muscle glycogen storage. *J Appl Physiol*. 1995;78:2187-2192.
116. Roy BD, Tarnopolsky MA. Influence of differing macronutrient intakes on muscle glycogen resynthesis after resistance exercise. *J Appl Physiol*. 1998;84:890-896.
117. Dunford M, Smith M. Dietary supplements and ergogenic aids. In: Dunford M, eds. *Sports Nutrition: A Practice Manual for Professionals*. Chicago, IL: American Dietetic Association, 2006;116-141.
118. Williams M. *Nutrition for Health, Fitness and Sport*. 5th ed. New York, NY: McGraw-Hill; 2006.
119. Bahrke M, Yesalis C. *Performance-Enhancing Substances in Sport and Exercise*. Champaign, IL: Human Kinetics; 2002.
120. Consumer health information for better nutrition: Task force final report. US Food and Drug Administration Center for Food Safety and Applied Nutrition Web site. http://www.cfsan.fda.gov/~dms/nuttftoc.html. Accessed June 20, 2008.
121. American Dietetic Association. Practice paper of the American Dietetic Association: Dietary supplements. *J Am Diet Assoc*. 2005;105:460-470.
122. Burke L. Supplements and sports foods. In: Burke L, Deakin V, eds. *Clinical Sports Nutrition*. Sydney, Australia: McGraw-Hill; 2006:485-579.
123. Bemben MG, Lamont HS. Creatine supplementation and exercise performance: Recent findings. *Sports Med*. 2005;35:107-125.

124. Volek JS, Rawson ES. Scientific basis and practical aspects of creatine supplementation for athletes. *Nutrition*. 2004;20:609-614.
125. Rawson E, Clarkson P. Scientifically debatable: Is creatine worth its weight? Gatorade Sports Science Institute Web site. http://www.gssiweb.com/Article_Detail.aspx?articleid=626. Accessed June 20, 2008.
126. Branch J, Williams M. Creatine as an ergogenic supplement. In: Bahrke M, Yesalis C, eds. *Performance-Enhancing Substances in Sport and Exercise*. Champaign, IL: Human Kinetics; 2002:175-196.
127. Branch JD. Effect of creatine supplementation on body composition and performance: A meta-analysis. *Int J Sport Nutr Exerc Metab*. 2003;13:198-226.
128. Terjung RL, Clarkson P, Eichner ER, Greenhaff PL, Hespel PJ, Israel RG, Kraemer WJ, Meyer RA, Spriet LL, Tarnopolsky MA, Wagenmakers AJ, Williams MH. American College of Sports Medicine roundtable. The physiological and health effects of oral creatine supplementation. *Med Sci Sports Exerc*. 2000;32:706-717.
129. Juhn MS, Tarnopolsky M. Potential side effects of oral creatine supplementation: A critical review. *Clin J Sport Med*. 1998;8:298-304.
130. Kreider RB, Melton C, Rasmussen CJ, Greenwood M, Lancaster S, Cantler EC, Milnor P, Almada AL. Long-term creatine supplementation does not significantly affect clinical markers of health in athletes. *Mol Cell Biochem*. 2003;244:95-104.
131. Mayhew DL, Mayhew JL, Ware JS. Effects of long-term creatine supplementation on liver and kidney functions in American college football players. *Int J Sport Nutr Exerc Metab*. 2002;12:453-460.
132. Poortmans JR, Francaux M. Adverse effects of creatine supplementation: Fact or fiction? *Sports Med*. 2000;30:155-170.
133. Groeneveld GJ, Beijer C, Veldink JH, Kalmijn S, Wokke JH, van den Berg LH. Few adverse effects of long-term creatine supplementation in a placebo-controlled trial. *Int J Sports Med*. 2005;26:307-313.
134. Graham T, Moissey L. Caffeine, creatine and food-drug synergy: Ergogenics and applications to human health. In: Thompson L, Ward W, eds. *Food Drug Synergy and Safety*. Boca Raton, FL: CRC Press; 2005.
135. Armstrong LE. Caffeine, body fluid-electrolyte balance, and exercise performance. *Int J Sport Nutr Exerc Metab*. 2002;12:189-206.
136. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Water, Potassium, Sodium, Chloride and Sulfate*. Washington, DC: National Academies Press; 2004.
137. Armstrong LE, Pumerantz AC, Roti MW, Judelson DA, Watson G, Dias JC, Sokmen B, Casa DJ, Maresh CM, Lieberman H, Kellogg M. Fluid, electrolyte, and renal indices of hydration during 11 days of controlled caffeine consumption. *Int J Sport Nutr Exerc Metab*. 2005;15:252-265.
138. Armstrong LE, Casa DJ, Maresh CM, Ganio MS. Caffeine, fluid-electrolyte balance, temperature regulation, and exercise-heat tolerance. *Exerc Sport Sci Rev*. 2007;35:135-140.
139. Alford C, Cox H, Wescott R. The effects of red bull energy drink on human performance and mood. *Amino Acids*. 2001;21:139-150.
140. Petrie H. Energy drinks: What you need to know. Gatorade Sports Science Institute and Dietitians of Canada 2006. http://www.coach.ca/admin/pdf_admin/pdf/energy-drinks_gssi_e.pdf. Accessed June 20, 2008.
141. Liguori A, Robinson JH. Caffeine antagonism of alcohol-induced driving impairment. *Drug Alcohol Depend*. 2001;63:123-129.
142. Crowe MJ, Leicht AS, Spinks WL. Physiological and cognitive responses to caffeine during repeated, high-intensity exercise. *Int J Sport Nutr Exerc Metab*. 2006;16:528-544.
143. Webster M. Sodium bicarbonate. In: Bahrke M, Yesalis C, eds. *Performance-Enhancing Substances in Sport and Exercise*. Champaign, IL: Human Kinetics; 2002.
144. Maughan RJ. Contamination of dietary supplements and positive drug tests in sport. *J Sports Sci*. 2005;23:883-889.
145. Pipe A, Ayotte C. Nutritional supplements and doping. *Clin J Sport Med*. 2002; 12:245-249.
146. Larson-Meyer D. *Vegetarian Sports Nutrition: Food Choices and Eating Plans for Fitness and Performance*. Champaign, IL: Human Kinetics; 2007.

To obtain references used for the evidence analysis sections of this position, go to www.eatright.org/cps/rde/xchg/ada/hs.xsl/advocacy_15986_ENU_HTML.htm.

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Authors: ACSM: Nancy R. Rodriguez, PhD, RD, CSSD, FACSM (University of Connecticut, Storrs). ADA: Nancy M. DiMarco, PhD, RD, CSSD, FACSM (Texas Woman's University, Denton). DC: Susie Langley, MS, RD, CSSD (Nutrition Consultant, Toronto, ON, Canada).

Reviewers: ADA: Sharon Denny, MS, RD (ADA Knowledge Center, Chicago, IL); Mary H. Hager, PhD, RD, FADA (ADA Government Relations, Washington, DC); Melinda M. Manore, PhD, RD, CSSD (Oregon State University Corvallis); Esther Myers, PhD, RD, FADA (ADA Scientific Affairs, Chicago, IL); Nanna Meyer, PhD, RD, CSSD (University of Colorado, Colorado Springs); James Stevens, MS, RD, (Metropolitan State College of Denver, Denver, CO); and Jennifer A. Weber, MPH, RD (ADA Government Relations, Washington, DC). DC: Rennie Benedict, MSc, RD (Department of Kinesiology & Applied Health, University of Winnipeg, Winnipeg, MB, Canada); Marilyn Booth MSc, RD (Registered Dietitian and Exercise Consultant, Ottawa, ON, Canada); Patricia Chuey, MSc, RD (Manager Nutrition Affairs, Overwaitea Food Group, Vancouver, BC, Canada); Kelly Anne Erdman, MSc, RD (University of Calgary Sport Medicine Centre, Calgary AB, Canada); Marielle Ledoux, PhD, PDt (Department of Nutrition, Faculty of Medicine, Université de Montréal, QC, Canada); Pamela Lynch, MHE, PDt (Nutrition Counseling Services & Associates; Mount Saint Vincent University, Department of Applied Human Nutrition, Halifax, NS, Canada); Elizabeth (Beth) Mansfield, MSc, RD, PhD Candidate (McGill University, Montreal, QC, Canada); and Heather Petrie, MSc, PDt (Nutrition Consultant, Halifax, NS, Canada). ACSM: Susan Barr, PhD, RDN (University of British Columbia, Vancouver, BC, Canada); Dan Benardot, PhD, RD, FACSM (Georgia State University, Atlanta); Jacqueline Berning, PhD, RD (University of Colorado Springs, Colorado Springs, CO); Andrew Coggan, PhD (Washington University School of Medicine, St Louis); Melinda Manore, PhD, RD (Oregon State University, Corvallis); and Brian Roy, PhD (Brock University, St Catharines, ON, Canada).

Association Positions Committee Workgroup: Christine M. Palumbo, MBA, RD (chair); Pat M. Schaaf, MS, RD; Doug Kalman, PhD, RD, FACN (content advisor); and Roberta Anding, MS, RD, LD, CSSD (content advisor).