AMERICAN COLLEGE
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AMERICAN DIETETIC ASSOCIATION
DIETITIANS OF CANADA

Nutrition and Athletic Performance

JOINT POSITION STATEMENT

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 the sports dietitian. 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 and to 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, the Board Certified Specialist in Sports Dietetics in the United States, should provide individualized nutrition direction and advice after a comprehensive nutrition assessment.

POSITION STATEMENT

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This ADA position paper uses ADA's Evidence Analysis Process and information from the ADA Evidence Analysis Library (EAL). Similar information is also available from DC's Practice-based Evidence in Nutrition (PEN). The use of an evidence-based approach provides important added benefits to earlier review methods. The major advantage of the approach is the more rigorous standardization of review criteria, which minimizes the likelihood of reviewer bias and increases the ease with which disparate articles may be compared. For a detailed description of the methods used in the evidence analysis process, access the 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 = a 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 purchasable at https://www.adaevidencelibrary.com/store.cfm. Subscriptions for DC and non-DC members are available for PEN at http://www.dieteticsatwork.com/pen_order.asp

KEY POINTS

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

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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 used as the sole criterion for participation in sports; daily weigh-ins are discouraged. Optimal body fat levels depend on 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 $g \cdot kg^{-1}$ body $weight \cdot d^{-1}$ (2.7–4.5 $g \cdot lb^{-1}$ body $weight \cdot d^{-1}$). Carbohydrates maintain blood glucose levels during exercise and replace muscle glycogen. The amount required depends on 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 $g \cdot kg^{-1}$ body $weight \cdot d^{-1}$ (0.5–0.8 $g \cdot lb^{-1}$ body $weight \cdot d^{-1}$). 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 $\leq$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 2–3% 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, approximately 16–24 oz (450–675 mL) of 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 30–60 $g \cdot h^{-1}$) for maintenance of blood glucose levels. These nutrition guidelines are especially important for endurance events lasting longer than an hour when the athlete has not consumed adequate food or fluid before exercise or when the athlete is exercising in an extreme environment (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 approximately 1.0–1.5 $g \cdot kg^{-1}$ body weight (0.5–0.7 $g \cdot lb^{-1}$) during the first 30 min and again every 2 h for 4–6 h 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 (e.g., 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 (Fig. 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 18–40 yr; all sport settings; and trained athletes, athletes in training, or individuals regularly exercising. Because the grading system used provides allowances 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 dropout rate could not exceed 20%. The publication range for the evidence-based analysis spanned 1995–2006. If an author was included in more than one review article or primary research articles that were similar in content, the most recent paper was accepted, and earlier versions were rejected. However, when an author was included in 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 40 yr, adults younger than 18 yr, 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, which were similar in content
- Articles not in English

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, caloric intake, and macronutrient intake for optimal athletic performance during training?
Competition	What is the evidence to support a particular meal timing, caloric intake, and macronutrient intake for optimal athletic performance during competition during the 24 hours prior to competition?
	What is the evidence to support a particular meal timing, caloric intake, and macronutrient intake for optimal athletic performance during competition?
Recovery	What is the evidence to support a particular meal timing, caloric 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 nutrition and athletic performance project.

Conclusion statements were formulated summarizing the strength of evidence with respect to each question (Fig. 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's 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 the skeletal muscles ($\sim$5 mmol·kg^{-1} 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 $\sim$3–5 min (2). The amount of creatine phosphate available in skeletal muscle is approximately four 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 the 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 60–180 s. Approximately 25%–35% of total muscle glycogen stores are used during a single 30-s 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 $\sim$2–3 min.

The oxidative pathway fuels events lasting longer than 2–3 min. 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 1500-m run, marathon, half-marathon, and endurance cycling or ≥1500-m 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 much ATP over time via the Krebs cycle and the electron transport system. The greater dependence on 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%–60% of energy during 1–4 h 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 the 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).

ENERGY REQUIREMENTS

Meeting energy needs is a nutrition priority for athletes. Optimum athletic performance is promoted by adequate energy intake. This section will provide 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 (BMR), the thermic effect of food, the thermic effect of activity (TEA), which is the energy expended in planned physical activity, and nonexercise activity thermogenesis (5). Spontaneous physical activity is also included in the TEA.

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 (e.g., <1800–2000 kcal·d^{-1}) 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, long-term 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 (RMR). 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^{-1} FFM·d^{-1} might be the lower threshold of energy availability for females (12–15).

Estimation of energy needs of athletes and active individuals can be done using a variety of methods. The Dietary Reference Intakes (DRI) (15,17) and the Dietary Guidelines 2005 (16) (http://www.health.gov/dietaryguidelines/dga2005/report/HTML/D3_Disccalories.htm) provide energy recommendations for men and women who are slightly to very active, which are based on predictive equations developed using the doubly labeled water technique that can also be used to estimate energy needs of athletes (Fig. 2).

Energy expenditure for different types of exercise is dependent on 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 calories 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 BMR or RMR. The two prediction equations considered to most closely estimate energy expenditure are the Cunningham equation (1980) (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, BMR or RMR is then multiplied by the appropriate activity factor of 1.8–2.3 (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 (METs) recorded during a 24-h period (20). Any of these methods can be used to estimate energy expenditure for the determination of energy intake requirements and provide the sports dietitian with a basis to guide the athletes or active individuals 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,

The DRI method for estimating energy requirements of an adult male =
$662 - 9.53(\text{age, yrs}) + \text{PA}\,[15.91(\text{weight in kg}) + 539.6(\text{height in meters})]$.

For an adult female estimated energy requirements =
$354 - 6.91(\text{age, yrs}) + \text{PA}\,[9.36\ (\text{weight in kg}) + 726(\text{height in meters})]$

Physical activity (PA) is defined below.

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

FIGURE 2—The Dietary Reference Intake (DRI) method for estimating energy requirement for adults (17).

and appearance. A lean body, i.e., 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 the improvement of athletic performance. Age, sex, genetics, and the requirements of the sport are factors that impact the 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 (DXA), and air displacement plethysmography are Level II techniques, and skinfold measurements and bioelectrical impedance analysis (BIA) are Level III techniques. Levels II and III techniques are used in practice by sports dietitians.

Underwater weighing, once considered the criterion standard, is no longer common. DXA, originally developed to assess bone mineral, can be used for body composition analysis (21). Although DXA is fairly accurate, quick, and noninvasive, the cost of and access to the instrument limits its use 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 equation of either Siri (23) or Brozek (24). Although this method provides valid and reliable assessment of body composition, it may underestimate body fat in adults and children by 2%–3% (25).

Two of the most commonly used Level III methods are skinfold measurements and BIA. In addition, measures of body weight, height, wrist and girth circumferences, and 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 et al. (22) and Marfell-Jones et al. (26). Prediction equations using skinfold measurements to determine body fat content are numerous (22). Approximately 50%–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 and standardization of skinfold sites 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 (USOC) is using the International Society for Advances in Kinanthropometry (ISAK) techniques (26) as efforts are underway to standardize measures worldwide. The USOC advocates using the sum of seven skinfolds (mm) based on ISAK landmarks, marking skinfold sites on the body, reporting duplicate measures, and communicating the results as a range, rather than percentage of 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). Bioelectrical impedance analysis is dependent on several 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 males and 12% for females (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 ISAK sum of seven skinfolds indicates that the range of values for the athletic population is 30–60 mm for males and 40–90 mm for females (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 with specific regard for performance, as well as body composition (i.e., loss of lean body mass). See Figure 3for practical guidelines for weight management of athletes.

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 intakewill 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" food 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. Modified with permission from: Manore MM. Chronic dieting in active women: what are the health consequences? *Womens Health Issues.* 1996;6:332–41.

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 Dietary Guidelines for Americans (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 proportions as a basis for meal plans for athletes. For example, when energy intake is 4000–5000 $\text{kcal}\cdot\text{d}^{-1}$, even a diet containing 50% of the energy from carbohydrate will provide 500–600 g of carbohydrate (or approximately 7–8 $\text{g}\cdot\text{kg}^{-1}$ (3.2–3.6 $\text{g}\cdot\text{lb}^{-1}$) 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 (100–125 $\text{g}\cdot\text{d}^{-1}$) could exceed the recommended protein intake for athletes (1.2–1.7 $\text{g}\cdot\text{kg}^{-1}\cdot\text{d}^{-1}$ or 84–119 g in a 70-kg athlete). Conversely, when energy intake is less than 2000 $\text{kcal}\cdot\text{d}^{-1}$, a diet providing 60% of the energy from carbohydrate may not be sufficient to maintain optimal carbohydrate stores (4–5 $\text{g}\cdot\text{kg}^{-1}$ or 1.8–2.3 $\text{g}\cdot\text{lb}^{-1}$) in a 60-kg (132 lb) athlete.

Protein. Protein metabolism during and after 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 recommended dietary allowance (RDA) is 0.8 $\text{g}\cdot\text{kg}^{-1}$ body weight and the acceptable macronutrient distribution range (AMDR) for protein intake for adults older than 18 yr is 10%–35% of total calories (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 DRI 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 $g \cdot kg^{-1} \cdot d^{-1}$ (29–31). These recommendations remain unchanged, although recent studies have shown that protein turnover may become more efficient in response to endurance exercise training (29,32). Ultra-endurance athletes who engage in continuous activity for several hours or consecutive days of intermittent exercise should also consume protein at or slightly above 1.2–1.4 $g \cdot kg^{-1} \cdot d^{-1}$ (32). Energy balance, or the consumption of adequate calories, 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 because of more efficient protein use (30,31). Recommended protein intakes for strength-trained athletes range from approximately 1.2 to 1.7 $g \cdot kg^{-1} \cdot d^{-1}$ (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 near 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 impact athletic performance (41,42), recommendations regarding protein supplementation are conservative and directed primarily at optimizing the training response to and the recovery period after exercise. From a practical perspective, it is important to conduct a thorough nutrition assessment specific to the 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 (AMDR) for fat is 20%–35% of energy intake (17). The Dietary Guidelines for Americans (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, 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, β-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-and-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, Vitamin B_6, Pantothenic Acid, Biotin, Folate, Vitamin 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 vitamin B_{12} are required for the production of red blood cells, for protein synthesis, and in tissue repair and maintenance including the CNS. Of the B vitamins, riboflavin, pyridoxine, folate, and vitamin 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 slightly 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 impact performance, severe deficiency of vitamin 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 DRI level (5 $\mu g \cdot d^{-1}$ or 200 IU for ages 19–49 yr) (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, β-Carotene, and Selenium

The antioxidant nutrients, vitamins C and E, β-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 long-term exercise produces a constant "oxidative stress" on the muscles and other cells (49) leading to lipid peroxidation of membranes. Although short-term exercise may increase levels of lipid peroxide by-products (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 concerning 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 (UL) for antioxidants because higher doses could be pro-oxidative with potential negative effects (46,64,68).

Vitamin C supplements do not seem 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 100–1000 mg of 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 (70).

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 1500 mg of elemental calcium and 400–800 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 females (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 (i.e., 18 mg and 8 mg, for men and women respectively).

The high incidence of iron depletion among athletes is usually attributed to inadequate energy intake. Other factors that can impact 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 3–6 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 impact 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 after an increase in plasma volume known as "dilutional" or "sports anemia" and may not respond to nutrition intervention. These changes seem to be a beneficial adaptation to aerobic training, which do not negatively impact 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 (i.e., less skeletal muscle fatigue) when iron supplementation was prescribed as 100-mg ferrous sulfate for 4–6 wk (76). Improving work capacity and endurance, increasing oxygen uptake, reducing lactate concentrations, and reducing 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, BMR, 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 females, are also at risk for zinc deficiency (79). The impact 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 UL 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 HDL cholesterol and nutrient imbalances by interfering with absorption of other nutrients such as iron and copper (47). Further, the benefits of zinc supplementation to physical performance have not been established.

Magnesium. Magnesium plays a variety of roles in cellular metabolism (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, and 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 UL for sodium ($2.3\ \text{g}\cdot\text{d}^{-1}$) and chloride ($3.6\ \text{g}\cdot\text{d}^{-1}$). Sports drinks containing sodium ($0.5\text{–}0.7\ \text{g}\cdot\text{L}^{-1}$) and potassium ($0.8\text{–}2.0\ \text{g}\cdot\text{L}^{-1}$), as well as carbohydrate, are recommended for athletes especially in endurance events (>2 h) (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/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 (ACSM) 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, ACSM 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 h before exercise, individuals should drink approximately 5–7 $mL\cdot kg^{-1}$ body weight (~2–3 $mL\cdot lb^{-1}$) 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 (e.g., 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 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 $L\cdot h^{-1}$ (83). In addition to water, sweat also contains substantial but variable amounts of sodium. The average concentration of sodium in sweat approximates 50 $mmol\cdot L^{-1}$ or approximately 1 $g\cdot L^{-1}$ (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 the individual athlete's sweat rate, exercise duration, and opportunities to drink (83). Readers are referred to the ACSM position stand for specific recommendations related to body size, sweat rates, types of work, etc., and are encouraged to individualize hydration protocols when possible (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 provides energy. Beverages containing 6%–8% carbohydrate are recommended for exercise events lasting longer than 1 h (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 greater than 8%.

Disturbances of fluid and electrolyte balance that can occur in athletes include dehydration, hypohydration, and hyponatremia (83). Exercise-induced dehydration develops because of 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 competing 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 (i.e., wrestling, boxing, lightweight crew, martial arts, etc.), 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 less than 130 $mmol\cdot L^{-1}$) 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, who run slowly, who sweat less, or who 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 16–24 oz (450–675 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 ensure 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 and 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 >2500 m (8200 ft) consequent to mandatory diuresis and high respiratory water losses, accompanied by decreased appetite. Respiratory water losses may be as high as 1900 $\text{mL}\cdot\text{d}^{-1}$ ($1.9\ \text{L}\cdot\text{d}^{-1}$) in men and 850 $\text{mL}\cdot\text{d}^{-1}$ ($0.85\ \text{L}\cdot\text{d}^{-1}$) in women (87,88). Total fluid intake at high altitude approaches 3–4 $\text{L}\cdot\text{d}^{-1}$ 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 seems 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 (bread, cereals and grains, legumes, milk/alternatives, vegetables, and fruits). Energy needs for many athletes will exceed the amount of energy ($\text{kcal}\cdot\text{d}^{-1}$) 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 for 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 h 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 near 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 level above 6 g $\text{carbohydrates}\cdot\text{kg}^{-1}$ 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 d followed by a high-carbohydrate diet (>65% of energy) for 3 d 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 before 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 near 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 of carbohydrate for meals consumed 3–4 h 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 (e.g., pancakes, juice, and scrambled eggs) 2–4 h before exercise or competition; however, others may experience severe gastrointestinal distress after 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 h before competition on athletic performance were evaluated. Of eight studies, six reported no significant effect of meal consumption 90 min to 4 h 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 before 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%–8%) to endurance performance in events lasting 1 h 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 carbohydrates$\cdot$kg^{-1} body weight$\cdot$h^{-1} (approximately 30–60 g$\cdot$h^{-1}) 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 pre-exercise 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 h of exercise is not as effective as consuming the same amount at 15- to 20-min intervals throughout the 2 h 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, seem 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 min show conflicting results on athletic performance. However, of 17 studies based on carbohydrate consumption during exercise lasting greater than 60 min, 5 reported improved metabolic response, and 7 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 pre-exercise 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 postcompetition or postexercise meal or snack depend on the length and intensity of the exercise session (i.e., whether glycogen depletion occurred) and on 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 after a 90-min 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-min run in the morning and a 3-h cycling workout in the afternoon needs to maximize recovery between training sessions. The postworkout meal assumes considerable importance in meeting this goal.

Timing of postexercise carbohydrate intake affects glycogen synthesis over the short term (110). Consumption of carbohydrates within 30 min after exercise (1.0–1.5 g carbohydrate$\cdot$kg^{-1} at 2-h intervals up to 6 h is often recommended) results in higher glycogen levels after exercise than when ingestion is delayed for 2 h (111). It is unnecessary for athletes who rest one or more days between intense training sessions to practice nutrient timing about glycogen replenishment provided sufficient carbohydrates are consumed during the 24-h period after the exercise bout (112). Nevertheless, consuming a meal or snack near the end of exercise may be important for athletes to meet daily carbohydrate and energy goals.

The type of carbohydrate consumed also affects postexercise glycogen synthesis. When comparing simple sugars, glucose and sucrose seem equally effective when consumed at a rate of 1.0–1.5 g·kg^{-1} body weight for 2 h; 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 h after a glycogen-depleting exercise as compared with the same amount of carbohydrates provided as foods with a low glycemic index (114). Application of these findings, however, must be considered in conjunction with the athlete's overall diet. When isocaloric amounts of carbohydrates or carbohydrates plus protein and fat are provided after endurance (115) or resistance exercise (116), glycogen synthesis rates are similar. Including protein in a postexercise meal, however, 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 0.8–1.0 g carbohydrates·kg^{-1} body weight·h^{-1}) during the recovery period increases plasma glucose and insulin concentrations and increases 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 h 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 the claims and scientific evidence. Although dietary supplements and nutritional ergogenic aids, such as 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 FDA responsible for evaluating and enforcing safety. In 2003, the US/FDA 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 FDA 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 (NHP). Products regulated in Canada as NHP must comply with Natural Health Products Regulations (2003) and manufacturers are allowed to make a full range of claims (structure/function, risk reduction, treatment, 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 (121,122). 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, athletes are responsible for the product they ingest and any subsequent consequences. Dietary supplements or ergogenic aids will never substitute for genetic makeup, years of training, and optimum nutrition.

Both national [National Collegiate Athletic Association (NCAA; www.ncaa.org), United States Anti-Doping Agency (www.usantidoping.org)] and international sports organizations [World Anti-Doping Agency (WADA; (www.wada-ama.org)] 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 which 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 Board Certified Specialists in Sports Dietetics (CSSD) who carefully evaluate the risk–benefit ratio, including a complete dietary assessment.

It is beyond the scope of this article to address the multitude of ergogenic aids used by athletes in North America. From a practical perspective, however, most ergogenic aids can be classified into one of four categories: 1. those that perform as claimed; 2. those that may perform as claimed but for which there is insufficient evidence of efficacy at this time; 3. those that do not perform as claimed; and 4. those that are dangerous, banned, or illegal and, therefore, should not be used (122).

1. **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-CP energy system such as sprinting and weight lifting but not for endurance sports such as distance running (32,117,126–128). Most of the researches on creatine have been conducted in a laboratory setting with male athletes.

The most common adverse 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. The potential ergogenic effects of caffeine may be more closely related to its role as a CNS 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, WADA moved caffeine from the restricted list to its Monitoring Programme. However, caffeine is still a restricted substance by the NCAA, where a positive doping test would be a caffeine level $>15\ \mu g \cdot mL^{-1}$ of 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). Adverse effects of caffeine are anxiety, jitteriness, rapid heartbeat, gastrointestinal distress, and insomnia, and it 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 adverse 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).

2. **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, β-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).

3. **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, γ-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 after appropriate scientific inquiry and evaluation. To date, however, none of these products has been shown to enhance performance and many have had adverse effects (122).

4. **Ergogenic aids that are dangerous, banned, or illegal**

The ergogenic aids in this category should not be used and are banned by WADA. Examples are androstenedione, dehydroepiandrosterone, 19-norandrostenedione, 19-norandrostenediol, and other anabolic, androgenic steroids, *Tribulus 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.

The Vegetarian Athlete

The Position Statement of the American Dietetic Association and Dietitians of Canada on vegetarian diets (2003) provides appropriate dietary guidance for vegetarian athletes. This article provides additional considerations for vegetarians who participate in exercise. Well-planned vegetarian diets seem 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 whether 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 that supply adequate energy is consumed (31). Protein quality is a potential concern for individuals who avoid all animal proteins such as milk and meat (i.e., 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 approximately 10% protein is advised (15). Therefore, protein recommendations for vegetarian athletes approximate 1.3–1.8 $g \cdot kg^{-1} \cdot d^{-1}$ (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 nonheme 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 (i.e., adolescence and pregnancy). Very low fat diets or avoidance of all animal protein may lead to a deficiency of essential fatty acids. Sport dietitians should educate novice vegetarian athletes on resources for menu planning, cooking, and shopping—especially high-quality plant protein combinations and acceptable animal sources (i.e., dairy and eggs) as well as foods rich in or fortified with key nutrients (calcium, vitamins D, B_{12}, and riboflavin, iron, and zinc) (52).

Roles and Responsibilities of the Sports Dietitian

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 impact health and performance
- Address energy balance and weight management issues
- Address nutritional challenges to performance (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
- 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
- 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 (CDR; 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 Certification Specialist in Sports Dietetics (CSSD) 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 (RD) status, maintenance of RD status for a minimum of 2 yr, and documentation of 1500 sports specialty practice hours as an RD within the past 5 yr. For more information, readers are referred to the following Web site: www.cdrnet.org/whatsnew/Sports.htm.

ADA/DC/ACSM position adopted by the ADA House of Delegates Leadership Team on July 12, 2000 and reaffirmed on May 25, 2004; approved by Dietitians of Canada on July 12, 2000 and approved by the American College of Sports Medicine Board of Trustees on October 17, 2000. The Coaching Association of Canada endorses this position paper. This position is in effect until December 31, 2012. ADA/DC/ACSM authorizes republication of the position, in its entirety, provided full and proper credit is given. Readers may copy and distribute this article, providing such distribution is not used to indicate an endorsement of product or service. Commercial distribution is not permitted without the permission of ADA. Requests to use portions of the position must be directed to ADA headquarters at 800/877-1600, ext 4835, or ppapers@eatright.org.

AUTHORS

- American College of Sports Medicine: Nancy R. Rodriguez, PhD, RD, CSSD, FACSM (University of Connecticut, Storrs, CT)
- American Dietetic Association: Nancy M. DiMarco, PhD, RD, CSSD, FACSM (Texas Woman's University, Denton, TX)
- Dietitians of Canada: Susie Langley, MS, RD, CSSD (69 McGill Street, Toronto, ON, Canada)

REVIEWERS

- American Dietetic Association:

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, OR)
Esther Myers, PhD, RD, FADA (ADA Scientific Affairs, Chicago, IL);
Nanna Meyer, PhD, RD, CSSD (University of Colorado, Colorado Springs, CO)
James Stevens, MS, RD (Metropolitan State College of Denver, Denver, CO)
Jennifer A. Weber, MPH, RD (ADA Government Relations, Washington, DC)

- Dietitians of Canada:

Rennie Benedict, MSc, RD (Department of Kinesiology & Applied Health, University of Winnipeg, Winnipeg, MB)
Marilyn Booth, MSc, RD (Registered Dietitian and Exercise Consultant, Ottawa, ON)
Patricia Chuey, MSc, RD (Manager Nutrition Affairs, Overwaitea Food Group, Vancouver, BC)
Kelly Anne Erdman, MSc, RD (University of Calgary Sport Medicine Centre, Calgary AB)
Marielle Ledoux, PhD, PDt (Department of Nutrition, Faculty of Medicine, Université de Montréal, QC)
Heather Petrie, MSc, PDt (Nutrition Cosultant, Halifax, NS)
Pamela Lynch, MHE, PDt (Nutrition Counseling Services & Associates; Mount Saint Vincent University, Department of Applied Human Nutrition, Halifax, NS)
Elizabeth (Beth) Mansfield, MSc, RD, PhD Candidate (McGill University, Montreal, QC)

American College of Sports Medicine:

Susan Barr, PhD, RDN (University of British Columbia, Vancouver, BC)
Dan Benardot, PhD, DHC, RD (Georgia State University, Atlanta, GA)
Jacqueline Berning, PhD, RD (University of Colorado Springs, Colorado Springs, CO)
Andrew Coggan, PhD (Washington University School of Medicine, St. Louis, MO)
Melinda Manore, PhD, RD (Oregon State University, Corvallis, OR)
Brian Roy, PhD (Brock University, St. Catharines, ON)
Assistance from Lisa M. Vislocky, PhD, University of Connecticut, Storrs, CT, in preparing the references is acknowledged.

APC WORKGROUP

Christine M. Palumbo, MBA, RD (chair); Pat M. Schaaf, MS, RD; Doug Kalman, PhD, RD, FACN (content advisor); Roberta Anding, MS, RD, LD, CDE, CSSD (content advisor).

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