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Dietary Reference Intakes for the macronutrients and energy: considerations for physical activity[1]

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Abstract: The Dietary Reference Intakes (DRIs) are the North American reference standards for nutrients in the diets of healthy individuals. The macronutrient DRI report includes the standards for energy, fat and fatty acids, carbohydrate and fiber, and protein and amino acids. Equations used to identify the Estimated Energy Requirement (EER) were also developed based on individual characteristics including levels of physical activity. The DRIs for the macronutrients are presented as Recommended Dietary Allowances (RDAs) or Adequate Intakes (AIs), as well as Acceptable Macronutrient Distribution Ranges (AMDRs), and were arrived at by considering both nutrient inadequacies and excesses. In addition, recommendations are made that would reduce the risk of chronic diseases, such as setting intake limits for added sugar; reducing cholesterol, saturated, and trans fatty acids consumption; and increasing levels of physical activity. As healthy individuals include those engaged in various levels of physical activity, the DRIs should apply to the athlete and address their macronutrient and energy needs. This paper summarizes the macronutrient DRI report as applied to the adult, with discussion of the dietary needs of those engaged in various levels of physical activity, including the athlete.

Key words: nutrition, requirements, guidelines, performance, human.

Résumé : Les apports nutritionnels de référence (DRIs) sont des valeurs nord-américaines de référence spécifiques aux nutriments compris dans le régime alimentaires des individus en santé. Les normes concernant les macronutriments incluent les besoins d'énergie, de gras et d'acide gras, de sucres et de fibres, de protéines et d'acides aminés. Les équations utilisées pour estimer les besoins d'énergie (EER) ont aussi été élaborées à partir des caractéristiques des individus et de leur niveau d'activité physique. Les apports nutritionnels de référence concernant les macronutriments sont indiqués par la ration alimentaire recommandée (RDAs), l'apport adéquat (AIs) et par l'étendue admise des proportions de macro-éléments (AMDRs); ces valeurs prennent en compte les apports insuffisants ou excessifs de nutriments. De plus, les recommandations sont telles qu'elles devraient réduire les risques de maladies chroniques par la présentation de limites quant au sucre ajouté, par la réduction du taux de cholestérol et de la consommation d'acides gras trans et saturés et par l'augmentation de la pratique de l'activité physique. Comme les individus en santé incluent ceux qui pratiquent divers niveaux d'activité physique, les apports nutritionnels s'appliquent aux athlètes sur le plan de leurs besoins en macronutriments et en énergie. Cet article présente sommairement les apports nutritionnels de macronutriments destinés aux adultes et analyse les besoins nutritionnels des individus pratiquant divers niveaux d'activité physique dont l'athlète.

Mots clés : nutrition, besoins, directives, performance, humain.

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Introduction

An Expert Nutrition Review Panel, consisting of both American and Canadian scientists selected by the National Academy of Sciences, was formed in 2000 to establish the Dietary Reference Intakes (DRIs) for macronutrients and energy (Institute of Medicine (IOM) 2005). By consensus, the panel's mission was, based on the current scientific literature, to update, replace, and expand upon the old Recommended Dietary Allowances (RDAs) in the United States (NRC 1989) and Recommended Nutrient Intakes (RNIs) in Canada (Health and Welfare Canada 1990). In 2002, the DRI report was released with new recommendations for healthy individuals for energy, dietary carbohydrates and

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fiber, dietary fats which include fatty acids and cholesterol, dietary protein, and the indispensable amino acids (IOM 2005). The report also addressed the importance and role of both the macronutrients and physical activity in supporting good health (IOM 2005). The significance of this aspect of the report is clearly illustrated in the title of the media announcement that accompanied its release that stated “Report offers new eating and physical activity targets to reduce chronic disease risk” (The National Academies 2002). Therefore, unlike previous nutrient recommendations (RDA 1989; Health and Welfare Canada 1990), the purpose of the DRIs is not only to prevent nutrient inadequacies, but also to provide a measure for evaluating nutritional excess and to promote health by reducing the risk of chronic disease (IOM 2005).

As the DRIs were designed to meet the needs of individuals who are healthy and free of specific diseases or conditions, they should be applicable to those engaged in various levels of physical activity. Furthermore, for the macronutrients, the panel was instructed to consider increased physical activity as a factor affecting requirements (IOM 2005). Therefore, the DRIs are appropriate for most healthy individuals including those that are considered “very” physically active. In general, the panel took the view that “with minor exception, dietary recommendations for athletes are not distinguished from the general population, or vice versa” (IOM 2005). However, since the athlete may have daily nutritional requirements that differ from the general population, owing to the nature of the activities in which they are involved (e.g., type, intensity, and duration), one must have an good understanding of the DRIs themselves (Barr 2006*a*), as well as how to use and apply them (Barr 2006*b*). For some athletes, it may be necessary to seek nutritional advice from a health professional such as a dietitian to tailor a balanced diet to meet their special needs.

This brief review will focus on the DRIs that have been set for the macronutrients and total energy in adult males and females, and how they may or may not be relevant or appropriate for the athlete. Of special interest to the athlete includes how the DRI panel addressed the controversy surrounding protein and amino acid requirements and its view on the need for macronutrient supplementation. Also, the predictive equations used to identify the Estimated Energy Requirement (EER) may not be applicable for many athletes.

The breadth of the DRI report limits the scope of the review to the adult reference standards (Table 1). However, DRIs for both sexes at all stages of the life cycle including infants, children, and the older adult also exist. Also, this review is not intended to provide guidance on food choices that meet the DRIs for macronutrients. For information on the macronutrient composition of individual foods, numerous sources exist both online (e.g., United States Department of Agriculture (USDA) 2005*a*) and in print (e.g., Pennington and Douglass 2005).

Acceptable Macronutrient Distribution Range (AMDR)

An important difference between macronutrients and micronutrients is that in addition to supplying nutrients to meet the body’s need for specific physiological functions, macronutrients also supply the energy required by the body. As individual macronutrients can to some extent substitute for one another as energy sources and still provide adequate amounts of required nutrients, there is a range of intakes for carbohydrates, fats, and protein, known as the AMDR, that is associated with reduced chronic disease (IOM 2005; Barr 2006*a*). However, consumption above energy requirement (i.e., EER) and thus excess of a particular macronutrient could result in health problems such as obesity, cardiovascular disease, and diabetes (see Chapter 11, IOM 2005).

The AMDRs in adults for carbohydrates, fats, and protein are 45%–65%, 20%–35%, and 10%–35% of total energy, respectively (IOM 2005). The rationale for setting the carbohydrate range was that below 45% of total energy it would be difficult to meet the Adequate Intake (AI) for fiber, since carbohydrate foods are our main source of fiber, as well as the requirements for other nutrients (e.g., certain vitamins). Above 65%, the energy from fat and protein intakes could be too low to meet nutrient needs (e.g., essential fatty acids and indispensable amino acids) and the risk of hypertriglyceridemia is increased (IOM 2005).

In addition to supplying the essential fatty acids, dietary fat is a major source of energy and assists in the absorption of vitamins and the development of tissues (e.g., structural component and precursor to essential compounds). Along with an AMDR for fat, AMDRs were established for the essential fatty acids at 5%–10% of total energy for the n-6 fatty acids (i.e., linoleic acid) and 0.6%–1.2% of total energy for the n-3 fatty acids (e.g., alpha linolenic acid, eicosapentaenoic acid, and docosahexaenoic acid).

The wide AMDR for protein ensures an adequate supply of nitrogen and indispensable amino acids that are required for the synthesis of proteins and nitrogen-containing compounds in the body, at the lower end (10% of total energy). At the upper end (35% of total energy), little evidence of adverse effects in adults exist at protein intakes below 40% of dietary energy. Protein poisoning, know also as rabbit starvation, had been reported by early North American explorers who consumed high protein diets in excess of 40% of total energy (IOM 2005).

The AMDRs differ somewhat from previous guidelines (NRC 1989; Health and Welfare Canada 1990), which recommended dietary intakes of 50%–55% of energy from carbohydrates and 30% or less from fat. Protein recommendations are essentially unchanged. Therefore, the AMDRs ranges are clearly more liberal, thus making them useful for dietary planning and application (Barr 2006*b*). Any macronutrient needs of an athlete should also fit within these ranges. However, consuming a diet within the AMDR does not guarantee that individual nutrient requirements have been met. Therefore, RDAs or AIs have been set for those specific nutrients.

Carbohydrates and fiber

Using maintenance of normal levels of glucose in the brain, determined by arterio–venous difference across the brain (Kety 1957; Sokoloff 1973), as the indicator of adequacy, an Estimated Average Requirement (EAR) for carbohydrate of 100 $g \cdot d^{-1}$ was set for all age groups excluding periods of pregnancy and lactation in which an additional

Table 1. Dietary reference standards for the macronutrients in adult males (M) and females (F) 19 to 50 years of age.

Nutrient	Sex/life stage[a]	RDA (g/d)	AI (g/d)	AMDR (%)
Carbohydrate	M and F	130		45–65
Total fiber	M		38[b]	
	F		25[b]	
Total fat	M and F			20–35
n-6 PUFA[c]	M and F / 19–30 years		17	5–10
	M and F / 31–50 years		14	5–10
n-3 PUFA[d]	M		1.6	0.6–1.2
	F		1.1	0.6–1.2
Protein	M	56[e]		10–35
	F	46[e]		10–35

Note: RDA, Recommended Dietary Allowance; AI, Adequate Intake; AMDR, Acceptable Macronutrient Distribution Range.

[a]Values apply to nonpregnant and nonlactating adult females and adult males (19–50 years of age) unless life stage group is defined.

[b]Based on 14 g of total fiber per 1000 kcal of energy.

[c]n-6 polyunsaturated fatty acids (PUFA) as dietary linoleic acid.

[d]n-3 polyunsaturated fatty acids (PUFA) as dietary alpha-linolenic acid.

[e]Based on 0.8 g of protein per kg body mass per day.

amount of carbohydrate is required (IOM 2005). By adding 2 standard deviations (SD), 130 $g \cdot d^{-1}$ is the RDA (IOM 2005). Carbohydrate intake for most individuals, including athletes, exceeds the RDA, as median intakes of carbohydrate range from 200–330 $g \cdot d^{-1}$ and 180–230 $g \cdot d^{-1}$ for men and women, respectively (Data from the *Continuing Survey of Food Intakes by Individuals 1994–1996*, 1998, referenced in IOM 2005). However, individuals on low-carbohydrate diets such as the Atkins diet, would not be meeting the RDA (Anderson et al. 2000). Although a Tolerable Upper Intake Level (UL) was not set, the panel did make a recommendation that consumption of added sugars should not exceed 25% of total energy. Added sugars were defined as sugars and syrups that are added to food during processing and preparation. Major sources of added sugars include soft drinks, cakes, cookies, pies, fruitades, fruit punch, dairy desserts, candy, and some sport drinks. Finally, no recommendations based on glycemic index and glycemic load were made; however, the slowing of carbohydrate absorption was recognized as a potentially important principal in preventing chronic diseases. Further research in this area was recommended (IOM 2005).

New to the DRI report are dietary recommendations for fiber based on evidence of its effects on lowering blood cholesterol and the risk of heart disease, as well as its role in maintaining blood glucose levels. A daily AI for total fiber, defined as a combination of dietary fiber (i.e., nondigestible carbohydrate and lignin intrinsic and intact in plants) and functional fiber (i.e., isolated nondigestible carbohydrates that have demonstrated beneficial physiological effects in humans), was set at 14 g/1000 kcal (1 kcal = 4.184 kJ). Current intakes of fiber in North America tend to be considerably below the AI (data from the *Continuing Survey of Food Intakes by Individuals 1994–1996*, 1998, referenced in IOM 2005). Excess fiber in the diet would result in decreased mineral bioavailability, gastrointestinal distress, and lower energy intake; however, a UL was not set because excess consumption is likely to be self-limiting.

Fat, fatty acids, and cholesterol

An AI or RDA were not set for total fat because of insufficient scientific data to determine a defined level of fat intake at which risk of inadequacy or prevention of chronic disease occurs. In the adult, AIs for the n-6 and n-3 polyunsaturated fatty acids range from 14–17 $g \cdot d^{-1}$ and 1.1–1.6 $g \cdot d^{-1}$, respectively. Both monounsaturated fat, such as oleic acid, and cholesterol are synthesized by the body, and therefore, they are not required in specific amounts in the diet (i.e., no AI or RDA). ULs were not set for total fat, different types of fatty acids, and cholesterol as intakes at which adverse events occur could not be established. The associated negative effects on lipid profiles (e.g., increased low-density lipoprotein cholesterol and decreased high-density lipoprotein cholesterol) of increasing intakes of dietary saturated and trans fatty acids, as well as cholesterol, resulted in the panel recommending that the intakes of these compounds be as low as possible while consuming a nutritionally adequate diet.

When considering physical performance, the report points out that athletes may not be able to train as effectively on short-term intakes (i.e., a few days) of a high-fat diet when compared to a high-carbohydrate diet (Helge 2000) as a lack of adequate carbohydrate in a high fat diet would not maintain endogenous glycogen stores. However, a high-fat diet, in which fat made up close to 70% of energy intake, did not appear to compromise endurance trained athletes (Goedecke et al. 1999), although this diet would not be a recommended dietary pattern since it exceeds the AMDR for total fat.

Protein and amino acids

In the nonpregnant or lactating adult, protein is required in the diet to maintain body nitrogen and a supply of indispensable amino acids owing to losses during protein turnover. The general criterion used to establish the EAR for protein in the adult was to determine the point at which the body is able to maintain body protein content at its current

Table 2. An example of energy needs and dietary protein intakes at two physical activity levels and three protein levels (within AMDR for protein) in an adult female.

Subject:	Female
	30 years old
	weight = 60 kg
	height = 1.65 m
	BMI = 22
EER [female, 19–30 years] = 354 – 6.91 × age[years] + PA × (9.36 × wt[kg] + 726 × ht[m])	
Where:	PA = 1.0 if PAL "sedentary" (1.00–1.39), where PAL = TEE/BEE
	PA = 1.12 if PAL "low active" (1.40–1.59)
	PA = 1.27 if PAL "active" (1.60–1.89)
	PA = 1.45 if PAL "very active" (1.90–2.50)
Example 1:	PA = sedentary – low active, therefore, EER of approximately 2000 kcal
	At 10% of energy from protein or 200 kcal from protein
	50 g protein / 60 kg = 0.83 $g \cdot (kg \cdot d)^{-1}$
	At 15% of energy from protein or 300 kcal from protein
	75 g protein / 60 kg = 1.25 $g \cdot (kg \cdot d)^{-1}$
	At 20% of energy from protein or 400 kcal from protein
	100 g protein / 60 kg = 1.67 $g \cdot (kg \cdot d)^{-1}$
Example 2:	PA = very active, therefore, EER of approximately 2700 kcal
	At 10% of energy from protein or 270 kcal from protein
	68 g protein / 60 kg = 1.13 $g \cdot (kg \cdot d)^{-1}$
	At 15% of energy from protein or 400 kcal from protein
	100 g protein / 60 kg = 1.67 $g \cdot (kg \cdot d)^{-1}$
	At 20% of energy from protein or 540 kcal from protein
	135 g protein / 60 kg = 2.25 $g \cdot (kg \cdot d)^{-1}$

Note: Elite athletes may require more energy (kcal) to maintain their body mass than provided in the "very active" designation. In such cases, the EER equation would not apply. AMDR, Acceptable Macronutrient Distribution Range; EER, Estimated Energy Requirement; PA, physical activity factor; PAL, physical activity level; TEE, total energy expenditure; BEE, basal energy expenditure.

level (i.e., maintenance of nitrogen balance) (IOM 2005). This daily value was 0.66 $g \cdot kg^{-1}$ body mass per day for adults (men and women 19 years of age and older), which resulted in an RDA of 0.80 $g \cdot kg^{-1}$. This is the same daily value as the 1989 RDA (NRC 1989) and slightly lower than the 1990 RNI of 0.86 $g \cdot kg^{-1}$ (Health and Welfare Canada 1990). With respect to special healthy populations, the panel examined existing literature addressing the protein requirements of both the vegetarian and the athlete. For the vegetarian, the panel concluded that the consumption of a varied diet consisting of complementary mixtures of plant proteins (e.g., grains and legumes) would provide sufficient protein to meet the body's needs, and thus no adjustment in the RDA was required. After reviewing the scientific literature investigating the protein needs of athletes, the panel stated: "In view of the lack of compelling evidence to the contrary, no additional dietary protein is suggested for healthy adults undertaking resistance or endurance exercise" (IOM 2005). Thus, the RDA for athletes is 0.80 $g \cdot kg^{-1}$, which differs from other current guidelines for the athlete (ADA 2000) and recommendations for the elite athlete (Tarnopolsky 2004). For example, a joint position statement of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine (ADA 2000) concluded that the daily recommended intakes for protein in the endurance and strength-trained athlete range between 1.2–1.4 and 1.6–1.7 $g \cdot kg^{-1}$, respectively. That the RDA for protein is not currently in line with other guidelines for the athlete, as well as a body of scientific research (reviewed by Phillips 2004; Tarnopolsky 2004), does not necessarily mean that the DRIs are incorrect (Phillips 2004; Tarnopolsky 2004). The DRIs are established based on the current state of scientific knowledge and the panel reaching a consensus (IOM 2005). Thus, the DRIs are by definition subject to change and refinement as new evidence becomes available. Furthermore, if one was to use the AMDR for protein (not the RDA) as a guide to formulating an adequate diet, an athlete would easily meet the higher protein recommendation values (1.2–1.7 $g \cdot (kg \cdot d)^{-1}$ suggested by other groups (ADA 2000) and research (Campbell et al. 1995; Lemon 1996) (Table 2). Diets low in protein (i.e., less than10% total energy) are also uncommon in North American and most individuals consume protein in amounts much greater than required (i.e., 1.5–2 times the RDA) (Metges and Barth 2000).

Also of interest to athletes is that no UL for protein in the adult was set as cause and effect relationships between high protein intakes and chronic diseases could not be established, although high protein intakes are implicated in accelerating the progression of existing pathological states (e.g., renal disease). However, not having a UL for protein does not mean that there is not a potential for adverse effects from high protein intakes from food or supplements. Additional research is required to study the long-term effects of high protein diets on blood lipids and coronary heart disease, as well as other chronic disease states (IOM 2005).

In the adult, EARs (thus RDAs) were established for all 9 of the indispensable amino acids. The RDA values were then used to develop amino acid scoring patterns (in

Table 3. Dietary reference standards for the indispensable amino acids (IAA) and amino acid scoring patterns in adults 19 years of age and older.

IAA	EAR (mg · (kg · d)$^{-1}$)	RDA (mg · (kg · d)$^{-1}$)	FNB/IOM pattern (mg · (g protein)$^{-1}$)
Histidine	11	14	18
Isoleucine	15	19	25
Leucine	34	42	55
Lysine	31	38	51
Methionine + cysteine	15	19	25
Phenylalanine + tyrosine	27	33	47
Threonine	16	20	25
Tryptophan	4	5	7
Valine	19	24	32

Note: Values apply to non-pregnant and non-lactating adult females and adult males. The amino acid scoring pattern is the recommended FNB/IOM pattern that was derived from EAR for amino acid/EAR for protein where the EAR for protein in the adult is 0.66 g per kg body mass per day. FNB/IOM, Food and Nutrition Board/Institutes of Medicine; EAR, Estimated Average Requirement; RDA, Recommended Dietary Allowance.

Table 4. Examples of walking equivalents at the various physical activity levels (PAL).

PAL category	PAL ranges	Walking equivalence at PAL midpoint (miles per day at 2–4 mph)[a]
Sedentary	1.0–1.39	
Low active	1.4–1.59	1.5, 2.2, 2.9
Active	1.6–1.89	5.3, 7.3, 9.9
Very active	1.9–2.5	12.3, 16.7, 22.5

Note: 1 mile = 1.61 kilometers.
[a]Additional energy to that required as part of normal daily life. The different miles per day values (low, middle, high) apply to 120, 70, and 44 kg individuals, respectively.

mg · (g protein)$^{-1}$) for various ages based on the recommended intake of dietary protein (Table 3). Using these amino acid scoring patterns with a correction factor for digestibility, the protein quality of different protein sources can be determined (known as the protein digestibility – corrected amino acid score or PDCAAS). The new RDAs for the indispensable amino acids, some of which are 2 to 3 times greater than previous requirement estimates, illustrate one of the most striking differences in the DRI report when compared to earlier guidelines (WHO/FAO/UNU 1985; NRC 1889; Health and Welfare Canada 1990). Using lysine as an example, the RDA is 38 mg · kg^{-1} whereas previous estimates were at ~12 mg · kg^{-1}. The change in requirement values is due to a combination of factors. The first is the use of different indicators of adequacy not previously available (Young 1987; Zello et al. 1995), owing to the lack of existing methodologies (e.g., indicator amino acid oxidation, 24 h amino acid balance) or methodologies being early in their development (e.g., amino acid oxidation), as approaches to determine amino acid need. The second factor involves reanalyzing previous scientific evidence (i.e., regression of nitrogen balance) in light of the more sensitive measures of adequacy (i.e., amino acid oxidation and 24 h amino acid balance) that are now available (IOM 2005).

The higher RDAs for the indispensable amino acids do not mean that North American diets are deficient in these nutrients. To ensure adequate amounts, the indispensable amino acids composition of dietary protein that is consumed should be approximately 30%. Good quality protein contains at least this amount so dietary supplementation of indispensable amino acids is not necessary (IOM 2005). This is also true for the athlete; however, a vegan athlete with limited lysine intake (which could occur if legumes were not the major source of protein) may be at risk for inadequacy if total protein intake is limited to the RDA. This could be compensated for by increasing protein intake to levels above the RDA, as would likely occur to meet the AMDR for protein (Barr and Rideout 2004).

Although certain amino acids (e.g., phenylalanine, glutamate, and arginine) have been studied extensively at higher intakes than found naturally in diets, the potential adverse effects of most amino acids and their dose responses are not well documented. Hence no values for ULs could be identified (IOM 2005). As with protein, the failure of setting ULs for individual amino acids should not be taken to imply that consumption of very high amounts of amino acids is safe (Garlick 2004).

Energy

The approach used to establish recommendations for energy has been discussed in a companion paper (Barr 2006*a*). The predictive equations for EER that resulted were based on sex, stage of life, size of the individual (i.e., height and weight), and level of physical activity (IOM 2005) (see Barr 2006*a* and Table 2 for examples). The physical activity level (PAL) categories were defined as sedentary, low active, active, and very active. As Table 4 illustrates, these PAL categories are suitable for most individuals; thus, the developed predictive equations can be used for estimating energy needs for individuals engaged in various physical activities of differing intensity and length. Yet, for several reasons, the use of these predictive equations for estimating energy needs is not appropriate for some elite athletes who train intensely for several hours per day. Elite athletes were not represented in establishing the predictive equations since PALs greater than 2.5 were excluded from the database (IOM 2005). The greatest physical activity (PA) factor included in the predictive equations is for individuals considered "very active" (PAL values 1.9 to 2.5), which would rule out some athletes engaged in activities of great intensity and (or) very long duration. Therefore, for the competitive athlete, the amount of dietary energy from the recommended "nutrient mix" (i.e., AMDRs) should be adjusted to achieve or maintain optimal body weight. The panel also recognized the need to balance intake and expenditure, which may include differing sizes and frequencies of meals over a wide range of body sizes, body compositions, and forms of exercise (e.g., female gymnast versus football lineman) (IOM 2005).

Physical activity

The DRI report also emphasizes the critical importance of physical activity and fitness in maintaining health (IOM 2005). For the first time, an expert nutrition review panel directed to establish the nutrient recommendations for North Americans has recommended levels of energy expenditure met by engaging in physical activity to maintain a lower risk of developing chronic disease. Furthermore, the panel suggested engaging in 1 h of moderately intense activities (defined as brisk walking) over a day as such activity is associated with preventing coronary heart disease and is also beneficial for weight maintenance.

Summary

With a few exceptions (e.g., EER), the report of the DRI panel for macronutrients and energy is applicable to varying levels of physical activity, and the DRI reference standards can be used for planning diets for athletic individuals and groups (see companion article, Barr 2006*b*). Furthermore, the reference standards for the macronutrients are in line with other guidelines for healthy eating, such as Canada's Food Guide for Healthy Eating (Health and Welfare Canada 1992) and the new Dietary Guidelines for Americans (USDA 2005*b*). Nonetheless, for the elite athlete consultation with a nutrition professional may be appropriate to ensure an adequate intake and balance of the macronutrients in relation to overall energy needs.

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