Recommended Proportions of Carbohydrates to Fats to Proteins in Diets

Henry C. Lukaski

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16.1 INTRODUCTION

Physically active people are concerned about their daily energy intake for various reasons. Individuals participating in endurance or resistance training, whose daily caloric intakes can exceed 5000 kcal (~21,000 MJ), may be anxious not only to obtain an adequate amount of calories to match those expended in training, but also to consume the proportion of macronutrients to promote training and heighten performance. In contrast, sedentary men and women who seek to attain a healthy body weight by adopting healthful eating plans and increasing physical activity are anxious about limiting total energy intake and adjusting the mixture of macronutrients to optimize health and well-being. Thus, the roles of dietary carbohydrate, fat, and protein, as well as the recommended intakes, remain topics of research interest not only to promote optimal performance among athletes, but also to support health and physical fitness in the general population.

The ability to perform mechanical work is a function of skeletal muscle, and factors that affect energy production in muscle directly impact the performance of physical activity. The immediate source of energy for muscle contraction is the hydrolysis of adenosine triphosphate (ATP) to yield energy. The ATP content in muscle is limited; it is estimated to be 5.5 mmol/kg, or ~3.4 g in 20 kg of skeletal muscle of a 70-kg man. This amount of ATP would be exhausted in a few seconds of high-intensity activity; thus, ATP is rapidly replenished. Most physical activities rely on a combination of carbohydrate and fat metabolism to refill ATP stores by using aerobic pathways, principally mitochondrial oxidative phosphorylation. Anaerobic ATP production, however, is necessary when oxidative phosphorylation cannot provide ATP in adequate amounts needed to meet demands for muscle contraction. A number of factors influence muscle fuel selection, including the amount of stored substrates in muscle, the training status of the individual, exercise conditions (i.e., intensity and duration), environmental conditions, and nutrient intake during the activity. Among these factors, the pre-exercise endogenous fuel stores, particularly carbohydrate, are likely to limit physical performance. Other dietary factors may influence performance and training. Adaptation to a high-fat diet is reported to promote endurance performance. Consumption of high-protein diets also is thought to promote muscle accretion and strength gain during resistance training.

This chapter succinctly describes the roles that the macronutrients play in facilitating exercise training and performance. Emphasis is placed on the relative amounts (percent daily energy intake and gram per kilogram body weight) of carbohydrate, fat, and protein consumed to promote optimal training and performance. A comparison of these guidelines (gram per kilogram body weight and percent energy) is provided.

16.2 CARBOHYDRATE AND PERFORMANCE

It is well accepted by sports dietitians and athletes that carbohydrate plays a key role in supporting physical activity because of the need to maintain blood glucose concentrations. Although body stores of energy are variable, available carbohydrate is very limited (Table 16.1). The practical importance of stored carbohydrate or
gycogen is that, after hydrolyzed, it forms glucose, which is either used in muscle cells or transported from the liver for use by other cells. If glucose is fully oxidized to carbon dioxide and water (aerobic glycolysis or tricarboxylic acid cycle), more ATP is formed (39 vs. 4 moles of ATP per mole of glycosyl units consumed) than with anaerobic glycolysis and lactate formation. Another advantage of carbohydrate as an energy source is that it requires less oxygen for complete oxidation than fat (fatty acids) and protein (amino acids) because carbohydrate contains a higher ratio of oxygen to carbon and hydrogen. Thus, under conditions of limited oxygen availability, such as high-intensity work, carbohydrate is the preferential fuel source. A final benefit of carbohydrate is that its storage in skeletal muscle can be upregulated by diet and training regimens. Dietary carbohydrate can be a limiting factor in promoting certain types of physical activity and performance.

### 16.2.1 Usual Carbohydrate Intake, Muscle Glycogen, and Performance

Physically active men and women commonly report carbohydrate intakes similar to weight-matched inactive adults (45 to 55% of daily energy intake, or ~5 g/kg body weight/day). In general, these intakes may be adequate to meet the carbohydrate needs of recreational or fitness athletes who participate in moderate levels of activity up to 1 h daily. In contrast, endurance athletes who train with more intense activities that deplete muscle glycogen may have greater carbohydrate needs to ensure adequate muscle glycogen concentrations.

Investigators generally agree that muscle glycogen stores limit physical work capacity and performance during prolonged, moderate- to high-intensity aerobic exercise (>70% peak VO2 uptake). Thus, accumulation and maintenance of adequate skeletal muscle glycogen during training requires consumption of a carbohydrate-rich diet on a daily basis. Generally, skeletal muscle glycogen concentrations are
100 to 120 mmol/kg wet weight (ww). Consumption of a 45% carbohydrate diet did not maintain muscle glycogen concentrations during high-intensity training, as they declined from 110 to 88 to 66 mmol/kg during 3 days of intense running training.\textsuperscript{10} In a comprehensive review, Sherman and Wimer\textsuperscript{11} extended these findings in other groups of endurance athletes and concluded that more than 45% dietary carbohydrate was needed to replenish muscle glycogen stores during training and to avoid performance decrements. More recently, additional evidence shows that daily carbohydrate intake exceeding 50% total energy intake maintains muscle glycogen during training and performance of athletes participating in anaerobic sports.\textsuperscript{12} Thus, amounts of dietary carbohydrate usually consumed by the population are inadequate to maintain muscle glycogen and performance of athletes.

### 16.2.2 Pre-Exercise Carbohydrate Ingestion

The importance of a pre-event meal or snack is to compensate for a lack of adequate carbohydrate in the previous day’s meals and ensure adequate glycogen stores in liver and muscle. Feedings are generally small but high in carbohydrate (200 to 300 g), moderate in protein, and low in fat and fiber. Findings of controlled studies reveal that 200 to 300 g of carbohydrate fed 3 to 4 h before testing improved various indices of cycling performance by 15 to 49%.\textsuperscript{13}

In contrast, the effect on performance of carbohydrate feeding 30 to 60 min before exercise is unclear. Although blood glucose concentrations increased after ingestion of carbohydrate,\textsuperscript{14} one study\textsuperscript{15} reported improved and others\textsuperscript{16,17} showed no effects on performance compared to controls. There was consensus of no adverse effects on performance. Sherman et al.\textsuperscript{18} reported a 15% improvement in cycling performance when cyclists consumed ~300 g of carbohydrate 4 h before the performance test. Thus, exogenous carbohydrate fed before exercise may be beneficial to individuals who have low glycogen stores.

### 16.2.3 Carbohydrate Ingestion during Physical Activity

Participation in moderate-intensity (65 to 80% peak VO\textsubscript{2} uptake) exercise for a prolonged duration (>90 min) leads to fatigue because of reductions in circulating glucose and tissue glycogen stores. Feeding carbohydrate during exercise delays fatigue by maintaining blood glucose levels, whereas the impact on muscle glycogen sparing is controversial.\textsuperscript{19,20} Regardless of the mechanism, carbohydrate feeding during prolonged moderate- to high-intensity exercise was beneficial. Male cyclists who consumed 400 g of exogenous carbohydrate increased their endurance performance by 1 h compared to placebo.\textsuperscript{19} Running trials with carbohydrate feedings also found improved performance. Men supplemented with 55 g of carbohydrate per hour had increased blood glucose concentrations and completed the last 5 km of a 40-km run faster than they did when running without carbohydrate.\textsuperscript{21} In an endurance trial on a treadmill (80% peak VO\textsubscript{2} uptake), men fed 35 g of carbohydrate per hour ran 23 min longer than they did when running without carbohydrate.\textsuperscript{22} Thus, consumption of exogenous carbohydrate during prolonged, intense physical activities benefits endurance performance.
The timing and rate of carbohydrate ingestion are also important considerations. If individuals wait until the onset of fatigue before consuming carbohydrate, they may not be able to absorb it quickly enough to avoid fatigue. Coggan and Coyle found that the latest that an individual can consume carbohydrate and prevent fatigue is 30 min before the onset of fatigue. Ingestion of ~50 g of carbohydrate during the first 60 min of a bout of exhausting exercise improved endurance to exhaustion 14% compared to a water placebo. Thus, consumption of carbohydrate during endurance exercise is recommended before the onset of subjective feelings of fatigue to enhance performance.

16.2.4 Carbohydrate Intake during Recovery

Depletion of muscle glycogen content is a significant limitation to recovery from training and competition performance. Muscle glycogen depletion can occur after prolonged (2 to 3 h), continuous (60 to 80% peak VO₂ uptake) training as well as brief, intense (90 to 120% peak VO₂ uptake), intermittent competition and training. Thus, repletion of muscle glycogen stores is a target for recovery from strenuous physical activity.

Muscle glycogen replacement can occur at modest levels of carbohydrate intake. Some investigators report that a moderate carbohydrate intake of 5 to 6 g/kg body weight is adequate to maintain muscle glycogen concentration (~100 mmol/kg ww) during training. Other findings indicate that a higher carbohydrate intake (10 vs. 5 g/kg/day) is needed to avoid a gradual depletion of muscle glycogen (33%) during repetitive endurance and sprint training with endurance athletes. Other findings emphasize the importance of increasing dietary carbohydrate on muscle glycogen replenishment and key aspects of training and performance. During an 11-day period of intensive training, competitive athletes fed higher carbohydrate (8.5 compared to 5.4 g/kg/day) maintained physical performance and positive mood state and sustained higher rates of carbohydrate oxidation during exercise sessions. These findings confirmed earlier observations of increased training intensity when ad libitum carbohydrate intake increased from 6.5 to 9 g/kg/day during a 7-day period. In a study of competitive rowers during 4 weeks of training, increased dietary carbohydrate (10 vs. 5 g/kg/day) was associated with enhanced muscle glycogen (~155 vs. ~120 mmol/kg ww) and greater improvement in power out (11 vs. 2%) in time trials. Overall, these findings demonstrate that trained athletes benefit from an increased carbohydrate intake during periods of intense training because of the maintenance or enhancement of muscle glycogen stores and an ability to sustain higher rates of carbohydrate oxidation during exercise.

16.2.4.1 Timing of Carbohydrate Intake

The optimal time for carbohydrate ingestion to replenish muscle glycogen stores is during the first hour after exercise. Factors such as selective activation of glycogen synthase by glycogen depletion, exercise-induced increases in insulin sensitivity, and permeability of muscle cell to glucose facilitate glycogen synthesis and accumulation. Ivy et al. found higher rates of glycogen storage (7.7 mmol/kg ww) when
carbohydrate was fed during the first 2 h of recovery compared to more typical rates of storage (4.3 mmol/kg WW) without feeding. This finding is important in sports where time between competitions is brief (4 to 8 h).

Whereas it is important to consume carbohydrate as soon as practical after exercise to maximize glycogen repletion, there is little consensus about size of portions to accomplish this goal. Neither number nor size of meals or snacks during the 24 h after exertion significantly affected muscle glycogen storage.\textsuperscript{35,36} However, rates of glycogen synthesis during the first 4 to 6 h of recovery were greater when a substantial amount of carbohydrate (10 g/kg) was fed in 16 hourly snacks compared to 4 large meals.\textsuperscript{36} Thus, total carbohydrate intake, not a pattern of intake, is a key factor in facilitating muscle glycogen recovery. Issues related to the practicality and comfort of the individual athlete to avoid gastric discomfort should be considered.

16.2.4.2 Glycemic Index and Muscle Glycogen Replenishment

Another practical consideration in the restoration of muscle glycogen is the type of carbohydrate that promotes glycogen storage. Knowledge that glucose and insulin facilitate glycogen synthesis leads to the hypothesis that carbohydrate sources with high or moderate, compared to low, glycemic index enhance glycogen repletion during recovery from intense exercise training. Early studies, which used foods that were classified as containing starches and simple sugars to influence muscle glycogen stores after heavy training, provided conflicting results.\textsuperscript{35,37} Burke et al.\textsuperscript{38} fed foods with accepted glycemic index values to trained endurance athletes during a 24-h period of recovery after intense training. As hypothesized, the high-glycemic-index foods increased muscle glycogen storage 30\% more than an identical amount of carbohydrate derived from low-glycemic-index foods. Subsequent studies have confirmed the benefit of high-glycemic-index carbohydrates in promotion of glycogen storage.\textsuperscript{39,40}

16.2.5 Guidelines for Carbohydrate Intake in Athletes

Nutritional strategies to provide adequate amounts of carbohydrate to ensure optimal muscle glycogen replenishment in physically active people have been proposed.\textsuperscript{25} It is recommended that a usual intake be 5 to 7 g/kg/day when training or activity is low or moderate intensity. To facilitate recovery after moderate to heavy endurance training, carbohydrate intake should be 7 to 12 g/kg/day. Under conditions of extreme training (i.e., in excess of 4 h daily), the target for carbohydrate intake is 10 to 12 g/kg/day. Regardless of workout intensity, the initial recovery period (0 to 4 h after exercise) should provide 1.0 to 1.2 g/kg/h at frequent intervals (15 to 30 min). The goal of this dietary regimen strategy is to achieve carbohydrate intakes to meet the fuel needs during physical training and to facilitate optimal levels of muscle glycogen stores between workout sessions and in preparation for competition.
16.3 D I E T A R Y  F A T  A N D  P E R F O R M A N C E

Participation in prolonged, moderate-intensity aerobic activities (i.e., running, cycling, swimming, etc.) requires both availability and oxidation of carbohydrate and fat regardless of training status. Body fat stores (blood lipids, adipose tissue, and intramuscular triglyceride depots) are a relatively abundant energy source, even among endurance athletes. Thus, factors that increase fat availability may promote endurance performance. Catecholamines stimulate mobilization of fat stores and also increase the activity of lipoprotein lipase that promotes uptake of glycerol and fatty acids from the circulation into muscle cells after 15 to 20 min of moderate-intensity exercise. Aerobic training impacts fuel metabolism by increasing fat oxidation while decreasing endogenous carbohydrate utilization, thus sparing glycogen, to meet energy needs. Thus, factors that increase fat (fatty acid and glycerol) oxidation during exercise have been investigated.

16.3.1 F A T  L O A D I N G  A N D  E N D U R A N C E  P E R F O R M A N C E

Consumption of diets with very high fat and low or no carbohydrate content leads to ketosis at rest and during activity. Adaptation to diets high in fat (>60% daily energy intake) in trained athletes has been associated with changes in time to exhaustion during endurance tests. In comparison to eucaloric, isonitrogenous diets high in carbohydrate and low in fat, consumption of low-carbohydrate, high-fat diets fed for periods of 1 to 3 days depleted muscle and liver glycogen stores and impaired work capacity and endurance performance.

Other reports, however, indicate that a longer period (>7 days) of ingestion of a high-fat, low-carbohydrate diet promotes metabolic adaptations that significantly increase during exercise; these adaptations compensate for the relative lack of carbohydrate to meet the energy needs of the activity. Trained individuals consuming high-fat (>60% daily energy intake), low-carbohydrate diets for 5 to 30 days have significantly increased rates of fat oxidation and decreased rates of muscle glycogen utilization during submaximal exercise (50 to 70% peak \( \text{VO}_2 \) uptake) compared with isocaloric, isonitrogenous, high-carbohydrate diets. Importantly, time to exhaustion during laboratory tests significantly increased. Although these findings have raised interest among competitive athletes, Burke and Hawley have criticized many technical aspects of these studies, such as the findings being obtained in laboratory and not competitive conditions, and concluded that the suggestion that high-fat, low-carbohydrate diets are beneficial to endurance performance should be viewed cautiously. Their concerns are supported by other reports in trained and untrained adults who did not improve performance after eating high-fat, low-carbohydrate compared to high-carbohydrate, low-fat diets for periods up to 4 weeks. Thus, the performance benefits of long-term adherence to a high-fat, low-carbohydrate diet remain controversial.
16.3.2 Post-Exercise Diet and Intramuscular Triacylglycerol (IMTG)

Accumulating evidence indicates that IMTG is an important fuel source during prolonged moderate exercise (up to 85% peak VO₂ uptake) in trained individuals. Studies using histochemical assays as well as proton magnetic resonance spectroscopy showed a significant reduction in the IMTG of the upper and lower leg after prolonged exercise in endurance-trained athletes.

Controlled dietary studies revealed that the composition of the post-exercise diet affects the rate of repletion of the IMTG stores. Consumption of a high-fat (68% total energy) diet enhanced IMTG accumulation (33 to 45 mmol/kg) with no recovery (31 to 28 mmol/kg), compared to a low-fat (5%) diet during a 24-h recovery period. Low-fat (20%), high-carbohydrate (65 to 70%) diets do not replete IMTG during 1 day of recovery after prolonged exercise in trained and untrained individuals. Despite evidence that dietary fat intake positively influences IMTG levels, limited data indicate a detriment in endurance and sprint performance in cyclists.

16.3.3 Dietary Periodization: Fat and Carbohydrate

Another nutritional strategy that seeks to simultaneously increase endogenous muscle fuel depots is dietary periodization. Endurance athletes adapt their muscles to a high-fat diet for 5 to 6 days, then switch to a very high carbohydrate diet (10 to 12 g/kg/day) and rest for 24 h to optimize glycogen content. The fat adaptation period results in a marked upregulation of muscle metabolic machinery to enhance fat oxidation and promote glycogen sparing in muscle. Unfortunately, there is no evidence that this dietary manipulation has any beneficial effects on physical performance.

16.4 Dietary Protein Needs

Protein from food and beverages plays diverse roles in maintaining body structure and functions. These roles include formation of bone, muscle, connective tissue, hormones, and enzymes, maintenance of fluid and electrolyte balance, transport of micronutrients, and some contribution as an energy source during and after physical activity. Amino acids, which make up protein, are used as an energy source. During periods of energy deficit, amino acids, mobilized principally from endogenous protein stores in soft tissues, become substrates for gluconeogenesis to prevent hypoglycemia. Amino acids, specifically the branched-chain amino acids, can be oxidized directly by muscle and converted to Krebs cycle intermediates to increase acetyl-CoA oxidation. Measurements of by-products of protein catabolism, such as urea and ammonia, in the blood and urine and in vivo assessments of oxidation of labeled amino acids, tyrosine and leucine, provide evidence that protein is used as an energy source during exercise. The contribution of protein and amino acids to total energy expenditure is relatively small (2 to 5%) during submaximal efforts but increases to 10% when carbohydrate is depleted during prolonged, intense activity.
16.4.1 Effect of Physical Activity on Protein Requirements

The impact of physical activity on protein needs has been determined principally by using the nitrogen balance method. This approach requires measurements of nitrogen intake and losses (urine and feces) to determine individual protein requirements in response to stressors such as physical activity. A positive balance suggests protein accretion, whereas a negative balance suggests a net loss of body protein.

Studies of adults participating in resistance training highlight the need for increased protein. Lemon et al., studied novice bodybuilders consuming two levels of dietary protein. The nitrogen balance was negative when protein intake was 0.99 g/kg/day, but positive with an intake of 2.62 g/kg/day. Regression analysis (nitrogen balance vs. protein intake) showed that an average protein intake of 1.43 g/kg/day was needed to achieve a 0 balance (i.e., no gain or loss of nitrogen); the apparent protein requirement (0 balance ± 2 SD) was calculated to be 1.6 to 1.7 g/kg/day. Other investigators reported similar estimates of protein needs during resistance training regardless of training status. The increased protein requirement apparently is needed to promote accretion of muscle mass to enable strength gains.

There are limited data of nitrogen balance in endurance athletes. Elite male endurance athletes required a protein intake of 1 to 2 mg/kg/day to produce a positive or 0 nitrogen balance during 12 weeks of intense training. Similar protein intake estimates (1.5 to 1.8 g/kg/day) were reported for cyclists during a simulation of the Tour de France and well-conditioned runners during training. Tarnopolsky compiled all of the nitrogen balance data for the subjects in these studies, performed regression analysis, and showed that an average protein intake of 1.09 g/kg/day was needed to achieve a 0 nitrogen balance; the apparent protein requirement (mean ± 2 SD) was determined to be 1.2 mg/kg/day for endurance athletes.

16.5 Translation of Dietary Reference Intakes (DRIs) for Energy to Physically Active People

The DRIs contain categories of reference values for nutrients that are provided to promote the health and well-being of the public. The Recommended Dietary Allowance (RDA) is the daily dietary nutrient intake sufficient to meet the nutrient requirement of nearly all (98%) healthy individuals of a particular sex and life stage group. The Adequate Intake (AI) is the recommended average daily intake level based on observed or experimentally determined estimates of nutrient intake by a group or groups of healthy people. The AI is used when an RDA cannot be calculated. The Estimated Average Requirement (EAR) is the average daily nutrient intake estimated to meet the requirement for half of the healthy individuals in a particular sex and life stage group. The Tolerable Upper Intake Level (UL) is the highest average daily nutrient intake that is likely to pose no risk of adverse health effects for almost all individuals in the general population. Although EAR and RDA values are available for carbohydrate and protein, Acceptable Macronutrient Distribution Ranges (AMDRs) for carbohydrate, fat, and protein, providing ranges of macronutrient intake expressed as a percentage of total energy intakes, were derived from inter-
TABLE 16.2
Examples of Macronutrient Content of Diets Containing Acceptable Macronutrient Distributions and Typical Intakes at Variable Energy Levels for Women (121 lb or 55 kg)

<table>
<thead>
<tr>
<th>Energy, kcal/day</th>
<th>2000</th>
<th>2000</th>
<th>2000</th>
<th>2500</th>
<th>2500</th>
<th>2500</th>
<th>3000</th>
<th>3000</th>
<th>3000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate, %</td>
<td>45&lt;sup&gt;a&lt;/sup&gt;</td>
<td>55&lt;sup&gt;b&lt;/sup&gt;</td>
<td>65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>45&lt;sup&gt;a&lt;/sup&gt;</td>
<td>55&lt;sup&gt;b&lt;/sup&gt;</td>
<td>65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>45&lt;sup&gt;a&lt;/sup&gt;</td>
<td>55&lt;sup&gt;b&lt;/sup&gt;</td>
<td>65&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>g/day</td>
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<td>275</td>
<td>325</td>
<td>281</td>
<td>344</td>
<td>438</td>
<td>338</td>
<td>413</td>
<td>488</td>
</tr>
<tr>
<td>RDA, g/day</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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</tr>
<tr>
<td>g/kg/day</td>
<td>4.1</td>
<td>5.0</td>
<td>5.9</td>
<td>5.1</td>
<td>6.3</td>
<td>7.9</td>
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<td>8.9</td>
</tr>
<tr>
<td>Fat, %</td>
<td>35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>30&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>g/day</td>
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<td>67</td>
<td>44</td>
<td>97</td>
<td>83</td>
<td>56</td>
<td>117</td>
<td>100</td>
<td>66</td>
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<tr>
<td>g/kg/day</td>
<td>1.4</td>
<td>1.2</td>
<td>0.8</td>
<td>1.7</td>
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<td>1.0</td>
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<td>1.2</td>
</tr>
<tr>
<td>Protein, %</td>
<td>35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>g/day</td>
<td>175</td>
<td>75</td>
<td>50</td>
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<td>262</td>
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<td>75</td>
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<tr>
<td>g/kg/day</td>
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<td>1.4</td>
<td>0.9</td>
<td>3.9</td>
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<tr>
<td>RDA, g/kg/day</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
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<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
</tbody>
</table>

<sup>a</sup> Distributions.

<sup>b</sup> Intakes.

vention trials and epidemiological evidence that suggest a role in either prevention or increased risk of chronic disease. Because macronutrients can be used, at least to some extent, interchangeably as sources of energy to support metabolism, ranges for macronutrients are recommended. The AMDRs for carbohydrate, fat, and protein are estimated to be 45 to 60, 20 to 35, and 10 to 35% of energy, respectively, for adults. The ADMR values are different for infants and children.

The challenge for physically active individuals is to translate nutritional guidelines into practical use. Examples of recommended intakes of macronutrients for adults are shown in Table 16.2 and Table 16.3. The RDAs for dietary carbohydrate and protein are far less than the AMDRs even at the lowest energy intake levels. Because of the key role that carbohydrate plays in facilitating training and performance, Burke and co-workers have emphasized the use of recommendations based on body weight rather than percentage total energy intake. It is clear that athletes require flexibility to meet carbohydrate needs within the context of energy needs and training. During periods of general training, carbohydrate intakes of 5 to 7 g/kg/day are recommended and may be achieved at AMDR levels. However, when compensation of depleted muscle glycogen is needed, greater amounts of dietary carbohydrate are required (7 to 10 g/kg/day) without excessive increases in total energy intake. The challenge of an athlete consuming a very high carbohydrate diet (i.e., 65% energy) and energy in excess of his or her needs can lead to gradual weight gain and eventual performance deficits. This problem may be overcome if carbohydrate intake is based on weight and not total energy intake. Thus, recom-
TABLE 16.3
Examples of Macronutrient Content of Diets Containing Acceptable Macronutrient Distributions and Typical Intakes at Variable Energy Levels for Men (176 lb or 80 kg)

<table>
<thead>
<tr>
<th>Energy, kcal/day</th>
<th>3000</th>
<th>3000</th>
<th>3000</th>
<th>4000</th>
<th>4000</th>
<th>4000</th>
<th>5000</th>
<th>5000</th>
<th>5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate, %</td>
<td>45a</td>
<td>55b</td>
<td>65a</td>
<td>45a</td>
<td>55b</td>
<td>65a</td>
<td>45a</td>
<td>55b</td>
<td>65a</td>
</tr>
<tr>
<td>g/day</td>
<td>338</td>
<td>413</td>
<td>488</td>
<td>450</td>
<td>550</td>
<td>650</td>
<td>562</td>
<td>688</td>
<td>813</td>
</tr>
<tr>
<td>RDA, g/day</td>
<td>130</td>
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<td>130</td>
<td>130</td>
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</tr>
<tr>
<td>g/kg/day</td>
<td>4.2</td>
<td>5.2</td>
<td>6.1</td>
<td>5.6</td>
<td>6.9</td>
<td>8.1</td>
<td>7.0</td>
<td>8.6</td>
<td>10.2</td>
</tr>
<tr>
<td>Fat, %</td>
<td>35a</td>
<td>30b</td>
<td>30a</td>
<td>35a</td>
<td>30b</td>
<td>35a</td>
<td>30b</td>
<td>30a</td>
<td>20a</td>
</tr>
<tr>
<td>g/day</td>
<td>117</td>
<td>100</td>
<td>67</td>
<td>156</td>
<td>133</td>
<td>89</td>
<td>194</td>
<td>167</td>
<td>111</td>
</tr>
<tr>
<td>g/kg/day</td>
<td>1.5</td>
<td>1.3</td>
<td>0.8</td>
<td>1.9</td>
<td>1.7</td>
<td>1.1</td>
<td>2.4</td>
<td>2.1</td>
<td>1.4</td>
</tr>
<tr>
<td>Protein, %</td>
<td>35a</td>
<td>15b</td>
<td>10a</td>
<td>35a</td>
<td>15b</td>
<td>10a</td>
<td>35a</td>
<td>15b</td>
<td>10a</td>
</tr>
<tr>
<td>g/day</td>
<td>262</td>
<td>113</td>
<td>75</td>
<td>350</td>
<td>150</td>
<td>100</td>
<td>438</td>
<td>188</td>
<td>125</td>
</tr>
<tr>
<td>g/kg/day</td>
<td>3.3</td>
<td>1.3</td>
<td>0.9</td>
<td>4.3</td>
<td>1.7</td>
<td>1.25</td>
<td>5.5</td>
<td>2.1</td>
<td>1.5</td>
</tr>
<tr>
<td>RDA, g/kg/day</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
</tbody>
</table>

* Distributions.

b Intakes.

Recommandations based on body weight, compared to percentage of total daily energy intake, have practical advantages.

The RDA for protein (0.8 g/kg/day) is less than the AMDR, except at the lowest energy intakes (Table 16.2 and Table 16.3). It remains controversial if the protein needs to support endurance or resistance training exceed the RDA value. If an individual selects a protein intake slightly exceeding the lowest AMDR value (i.e., >10% energy intake), there is an expectation that the protein intake, when normalized for body weight (i.e., >1.1 g/kg/day), will boost strength gain and muscle mass maintenance.65 It is clear that protein intakes at the extreme levels of the AMDR are excessive and potentially a health hazard.

Recommendations for dietary fat have been proposed to avoid risks of future chronic disease. There is a paucity of data supporting an intake of fat that promotes performance. Assuming that the lowest level of the AMDR is healthful, dietary fat intakes of 1 to 1.5 g/kg appear to be adequate. Importantly, elite male cyclists consuming dietary fat at 30 to 50% total energy had increases in serum cholesterol and lipoprotein concentrations similar to those of sedentary adults.72

16.6 CONCLUSIONS

Experimental findings and practical outcomes emphasize the importance of an athlete's daily diet on performance. Because carbohydrate and fat are the principal sources of energy during physical training and competition, there has been an
emphasis on the critical evaluation of dietary manipulations of these macronutrients on performance. There is consensus that increased carbohydrate intake before, during, and after exercise affects performance and recovery after training. In contrast, although high dietary fat may transiently enhance some aspects of physiological function during controlled laboratory studies, fat loading does not benefit endurance performance in the field. Protein, consumed at usual intakes, exerts no clear benefit in endurance or resistance training or performance. However, neutral or positive nitrogen balance is important in maintaining and increasing muscle mass. Consumption of excessive energy, regardless of macronutrient distribution, can limit performance and impair biomarkers of health.

Guidelines for macronutrient intakes of physically active people are complicated by the units used to express the recommended intakes. Individual macronutrient recommendations based on the percentage of total energy intake vary directly with the total calories consumed. Thus, alterations in daily energy intake affect the intake of the macronutrient. It is also confusing and tedious for individuals to consistently calculate carbohydrate needs when total energy intake is variable. A more practical approach is to use targeted amounts of carbohydrate based on body weight. Similarly, protein intake can be planned easily when intakes are designated on a body weight basis. For both carbohydrate and protein, desired intakes can be estimated from tables summarizing the macronutrient contents of foods, particularly foods desirable to the athlete. Thus, athletes should be instructed by sports dietitians to use standard food guides to estimate carbohydrate and protein intakes based on body weight. Fat intake should be flexible but not excessive.

16.7 FUTURE RESEARCH

The growing public health emphasis on increasing physical activity and consumption of a healthful diet to combat the epidemic of obesity demands renewed efforts to translate dietary recommendations into action. Although the DRP and ADMR provide guidelines for macronutrient intakes, there is a compelling need to develop, validate, and implement practical guidelines for these intakes. It is important to determine if the recommended intakes achieve better compliance based on percentage energy intake than on body weight. Also, the availability of the Dietary Guidelines for Americans 2005 (http://www.healthierus.gov/dietaryguidelines) with its implementation plan, Food Guide Pyramid, appears to be a possible tool to evaluate the ADMR. Overall, the challenge is to develop practical methods for general implementation of national nutritional guidelines for macronutrient intake among all segments of the population.

REFERENCES


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