CHAPTER

36

Requirements of Energy, Carbohydrates, Proteins and Fats for Athletes

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ENERGY REQUIREMENTS

Introduction to Energy Needs

The central component of success in sport begins with adequate energy intake to support caloric expenditure and promote the maintenance or improvement in strength, endurance, muscle mass, and health. Athletes consuming a well-designed diet that includes both adequate amounts and proportions of the macronutrients (carbohydrates, proteins, and fat) will promote peak performance [1,2]. Inadequate energy intake relative to energy expenditure will reduce athletic performance and even reverse the benefits of exercise training. The result of limited energy will cause the body to break down fat and lean tissue to be used as fuel for the body. Meanwhile, inadequate blood glucose levels will increase fatigue and perception of exercise effort and ultimately reduce performance. Over time this could significantly reduce strength and endurance performance, as well as compromise the immune system, endocrine, and musculoskeletal function [3]. Additionally, sport-specific energy requirements vary greatly between sports where sport-specific energy needs should be determined, but overall athletes and coaches are highly encouraged to focus upon daily energy intake before concerning themselves too much with optimal intakes of the macronutrients.

Estimating Energy Needs of Athletes and Active Individuals

Estimation of energy needs for active individuals as well as athletes can be done using several resources. Typically in the field, an accessible as well as practical way to estimate energy expenditure of an athlete or active individual is to use prediction equations that have been developed based on assessments of resting metabolic rate and energy cost of physical activity (see Table 36.1) [3]. It is important to keep in mind during assessment that height, weight, age, body composition, and gender will influence caloric expenditure and alter the quantification of daily caloric needs, thus the initial computed outcome from these predictive approaches should be viewed as a general guideline or simply a starting point and not a final and conclusive number. Athletes and coaches should always measure height and weight when utilizing a predictive equation. Ideally, those wanting to quantify their personal resting metabolic rate without the use of a prediction equation can have it assessed using indirect calorimetry. Measuring resting metabolic rate using this preferred approach, however, can be costly to athletes, and it may become difficult to find a credible laboratory or location for all athletes to be measured using standardized conditions (e.g., fasting state, no recent stressful bouts of exercise, refrain from caffeine, alcohol, nicotine, etc.).

Once resting energy expenditure has been estimated using an appropriate prediction equation or measured, the value is then multiplied by the daily total energy expenditure. For simplicity, a physical activity level (PAL) factor is applied in order to average the daily total energy expended (see Table 36.1) and are intended to adjust daily energy intake needs relative to the individual's activity level. Typically, individuals who participate in recreational exercise or an overall fitness program (30 to 45 min/day, 3 to 4

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TABLE 36.1 Mifflin-St Joer [4] and Harris-Benedict [5] Resting Metabolic Rate Prediction Equation and Physical Activity Level (PAL) Factors.

Mifflin-St Joer	
Men	RMR = (9.99 × weight in kg) + (6.25 × height in cm) − (4.92 × age) + 5
Women	RMR = (9.99 × weight in kg) + (6.25 × height in cm) − (4.92 × age) + 161
Harris-Benedict	
Men	RMR = 66.47 + (13.75 × weight in kg) + (5.0 × height in cm)−(6.75 × age)
Women	RMR = 665.09 + (9.56 × weight in kg) + 1.84 × height in cm)−(4.67 × age)
Physical Activity Level (PAL) factors[a]	
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 @ 5−7 km/hour)
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.

[a]*Each factor is associated with a range that is intended to be viewed as a general starting point rather than a specific ending point. Manipulation within each range should be performed and should be performed on a largely individual basis.*
RMR, resting metabolic rate.
From Dietary Reference Intake (DRI) [6] and other sources [1,7].

times/week) do not typically need to alter their daily intake to meet nutritional needs. A typical diet of 25 to 35 kcal kg^{-1} day^{-1}, or approximately 1800 to 2400 calories per day, will likely be sufficient for a recreational athlete because caloric expenditure demands from exercise are not large (i.e., 200 to 400 kcal/session). However, athletes who are involved in moderate levels of exercise training for longer durations (i.e., 2 to 3 hours/day) multiple times per week (5 to 6 times/week), or high-intensity power or resistance training (3 to 6 hours/day) comprised of high-intensity or high-volume training multiple times per week (5 to 6 times/week) can expend 600 to 1200 or more kcal/hour of exercise [8,9].

Energy Needs of Endurance Athletes

Depending on the training schedule and exercise intensity of an endurance athlete, field research has documented hourly caloric expenditure in the range of 600 to 1200 kcal/hour. Consequently, estimated energy needs of such athletes are routinely in the range of 50−80 kcal kg^{-1} day^{-1}[8,9]. This means that depending on body size, a 50−100 kg endurance athlete will need to consume 2500 to 8000 calories per day in order to maintain energy balance to promote optimal endurance training and recovery. Extensive research has investigated the importance of ensuring adequate caloric intake for endurance athletes in order to maintain energy substrate during exercise, for mental function as well as muscular contraction. However, to delay the onset of fatigue from endurance activity, repletion of calories may be necessary during a training bout lasting longer than 60 to 90 minutes. Field research with ultra-endurance athletes recommends caloric intake to range from 100 to 430 calories per hour to maintain force output during exercise for endurance athletes [10].

Energy Needs of Strength and Power Athletes

Energy intake recommendations for strength and power athletes (i.e., sprinters, team sport athletes such as American football or rugby, weightlifters, throwing athletes, and bodybuilders) can vary greatly from those for endurance athletes. Unlike endurance athletes, quantification of caloric expenditure is much harder to determine for strength and power athletes, because of the variability in high-intensity bursts and power, varying lengths of recovery periods from training and competition, and a significant contribution of eccentric contractions which are known to instigate greater muscle damage and compromised recovery [11−13]. Similar to endurance athletes, caloric recommendations should be determined based on individual needs and goals as well as age, height, and weight (see Table 36.1). High-intensity activity requires a high level of energy production, typically followed by periods of rest intervals, which will create periods of high caloric expenditure to periods of recovery. For example, a sprint athlete during a 100-meter dash will perform for approximately 10 seconds or less supra-maximally followed by a recovery period. The ability of the athlete to recover between supra-maximal bouts can influence performance during training or competition. The variability in training volume, duration, and recovery periods adds to the complexity of energy needs and associated global recommendations of energy requirements for these athletic populations. Regardless, ensuring adequate energy balance will optimize force production per active bout, whether it is a sprint or weight workout, and will aid in optimal recovery.

Elite strength and power athletes utilize intermittent bouts of high-intensity force output or high-volume repetitive muscle contractions 3 to 6 hours/day up to 5 to 6 times/week. They can expend 600 to 1200 calories or more per hour of exercise [8,9]. The typical range of caloric expenditure per minute can be from 5.2 to 11.2 kcal/minute [9]. Variability occurs with body size, gender, age, amount of muscle mass activated during the lift, number of sets and repetitions completed, rest periods given, and time the contraction is held. Given the extreme muscularity of most strength athletes and the relationship between amount of muscle mass and total energy expenditure, it is not surprising that the current recommendations for energy intake range from 44 to 50 kcal kg^{-1} day^{-1} [9,14], particularly when one also considers that most of these athletes also seek to induce skeletal muscle hypertrophy, a process which demands even more energy.

Additional Considerations for Optimal Energy Intake

Regardless of athletic type, highly trained athletes who perform multiple bouts of high-volume, moderate- to high-intensity workouts each week have enhanced energy needs. Due to these increased energy demands in combination with other social or sport-specific factors, the athlete may be reticent about ingesting such large quantities of food for fear of the associated changes (perceived or real) to their bodies and physique. These concerns, in addition to the immense logistical planning which must be completed by the athlete and coaches to optimally meet energy needs can result in suboptimal energy intake. As mentioned previously in this section, inadequate energy intake puts the human body in a situation where it must unfavorably allocate various nutrient supplies to meet everyday cellular demand, which in the case of an exercising athlete can result in altered protein metabolism, poor recovery, and other associated outcomes linked to over-reaching/under-recovery. In this respect, the athlete and coach should be readily aware of this possibility and take great measures to ensure adequate energy as well as optimal amounts and ratios of the macronutrients are ingested, a point which will be developed in greater detail in the remaining sections.

CARBOHYDRATES

Structure and Function of Carbohydrates

Particularly in the context of increased energy demands from physical activity, carbohydrates are one of the most important nutrients for an exercising athlete. Carbohydrates serve as the primary fuel for working muscles during exercise, particularly as the intensity of exercise increases [15]. Moreover, carbohydrate in the form of glucose is often viewed as the exclusive fuel source for tissues such as the brain, spinal cord, and red blood cells. Generally speaking, the proportion of carbohydrates in the human diet is recommended to be around 55% of total calories, with an absolute daily requirement of 100–120 grams, but as will be explained in greater detail, the carbohydrate needs for endurance and resistance athletes surrounding workouts have much greater specificity.

Carbohydrate Types and Quality

Carbohydrates are found in the diet as grains, fruits, beans, legumes and dairy products and collectively are comprised of sugar units called saccharides. A common way of categorizing carbohydrates is based upon the number of saccharide units (e.g., mono-, di-, oligo- and polysaccharides) found within the overall carbohydrate molecule. The predominant forms of carbohydrate in the human diet are polysaccharides in the form of starch. This basis has also created a simple but easy to grasp concept of qualitatively assessing the complexity of a carbohydrate whereby mono- and disaccharides are commonly referred to as "simple" sugars and oligo- and polysaccharides are referred to as "complex" carbohydrates. While overly simplistic, this paradigm has meshed well with glycemic index and glycemic load, the most widely accepted means of objectively assessing carbohydrate quality.

Briefly, glycemic index refers to a rating or score assigned to a food that reflects the change in blood glucose which occurs after ingesting a standardized amount of carbohydrate of the food in question, relative to that for an identical amount of a standard test food such as white bread or pure glucose. Importantly, ratings have been established for a wide variety of carbohydrate-containing foods and, even though its application and utility have been met with much confusion and misuse, it remains as both the most recognized and accepted means of evaluating carbohydrate quality. Glycemic load refers to a number assigned to a food or meal that considers both the glycemic index of that particular food and the carbohydrate content of the food in question.

Carbohydrate Recommendations for Endurance Athletes

There is a great range of carbohydrate recommendations for an athlete, which depend largely upon intensity and duration of exercise. According to a recent position statement and other recent review articles, a recommended carbohydrate intake for athletes is $6-10\ g\ kg^{-1}\ day^{-1}$ [1,3,8,16,17]. Importantly, as exercise intensity increases, so does the reliance on carbohydrates for energy—research has shown that approximately 50−60% of energy substrate utilization during 1−4 hours of continuous exercise at 70% VO_{2max} is derived from carbohydrates [15]. As endurance training proceeds, energy expenditure does not change, but the reliance on carbohydrate decreases in favor of lipids at any given exercise intensity [15]. Ensuring adequate carbohydrate intake is necessary to guarantee adequate glycogen concentration, and strategies exploiting both the composition and timing of carbohydrate intake can have an effect on glycogen stores within the muscle and liver. Specifically, increasing glycogen stores within the muscle can play an influential role on carbohydrate availability during exercise and subsequent exercise performance.

Utilization of a high-carbohydrate diet in endurance athletes will promote elevated glycogen stores. In endurance sports lasting >90 minutes, it is suggested that super-saturated glycogen stores within the muscle will improve performance for low- to moderate-intensity long-duration exercise. To maximize glycogen refueling in preparation for a race or to maximize recovery following an intense training session, endurance athletes should consume approximately $7-10\ g\ kg^{-1}\ day^{-1}$. Manipulating the timing of carbohydrate intake and type of carbohydrate in preparation for a race or intense training may provide advantages metabolically during the race as well as following the race for refueling. Carbohydrate recommendations for both endurance and strength and power athletes are summarized in Table 36.2, and subsequent sections will further detail strategies to meet carbohydrate requirements surrounding a workout or competitive bout.

Carbohydrate Recommendations for Strength and Power Athletes

Consuming adequate carbohydrates for strength and power athletes is vital for optimal power output and overall performance. Intense intermittent muscle contractions lasting 1−5 minutes in duration, using exercises that recruit large masses of muscle, combined with short rest intervals can decrease glycogen stores by 24−40% [19−22]. Certainly the magnitude of muscle glycogen depletion depends on the intensity, duration, and amount of muscle mass that is recruited during the training session. It is commonly recommended that strength and power athletes who utilize training regimens that include high repetitions with a moderate to high level of resistance to maximize both strength and power adaptations as well as muscle hypertrophy will deplete greater concentrations of glycogen. For these reasons, an intake of $5-10\ g\ kg^{-1}\ day^{-1}$ is sufficient to maintain optimal glycogen stores in strength and power athletes [18].

Carbohydrate Intake for Pre-Training/Pre-Competition

The ideal pre-competition meal should contain 150 to 300 grams of carbohydrate (3 to $5\ g\ kg^{-1}$ body weight) approximately 3 to 4 hours prior to exercise. This amount consumed prior to exercise will maximize muscle and liver glycogen stores and help to sustain blood glucose concentrations throughout prolonged bouts of moderate- to high-intensity exercise [23]. Additional considerations for the pre-exercise meal include food choices that contain little fat and fiber, to maximize gastric emptying and minimize gastric upset.

Carbohydrate Intake During Exercise

Moderate- to high-intensity exercise is characterized by high oxidation rates of carbohydrate whereby such values have commonly been reported to be in the

TABLE 36.2 Average Macronutrient Requirements for Athletes[a].

	Endurance Athletes	Strength Athletes
Carbohydrates[b]	$6-10\ g\ kg^{-1}\ day^{-1}$	$3.9-8.0\ g\ kg^{-1}\ day^{-1}$
Protein[b]	$1.2-1.4\ g\ kg^{-1}\ day^{-1}$	$1.2-1.7\ g\ kg^{-1}\ day^{-1}$
Fat	20−30% of Total Energy Intake (10% saturated, 10% polyunsaturated, 10% monounsaturated)	20−30% of Total Energy Intake (10% saturated, 10% polyunsaturated, 10% monounsaturated)

[a]*Variability depends on sport or mode, intensity, duration, and skill of the athlete.*
[b]*kg represents kilogram body weight.*
Adapted from Genton et al [18], The Institute of Medicine Guidelines 2005 [9], and The ADA/ACSM Position on Nutrition and Athletic Performance [1,17].

order of 1.0–1.2 grams of carbohydrate per minute (60–72 grams per hour) of exercise [24,25]. At these rates, high-intensity endurance exercise (e.g., >70% VO_{2max}) that lasts approximately 1 hour can exhaust liver glycogen stores and significantly deplete muscle glycogen stores in as little as 2 hours. For these reasons, optimal repletion of carbohydrates and energy is vital to continue exercise and/or maintain force output. According to research done with endurance athletes, it is recommended that 60 grams or 0.5–1.0 g kg^{-1} of liquid or solid carbohydrates be consumed each hour of moderate- to higher-intensity endurance exercise lasting longer than 1 hour [3,16]. Moreover, decades of sport nutrition research tells us that glucose-electrolyte solutions which deliver carbohydrate concentrations of 6–8% carbohydrate (6–8 grams of carbohydrate per 100 mL of fluid) offers the ideal balance between non-episodic gastric emptying and efficient energy delivery [3,24]. These solutions are recommended to be ingested every 15 to 30 minutes, which effectively provides a continual supply of carbohydrate to the working muscles. A host of positive effects arise from this strategy, including an optimal maintenance of blood glucose levels which aids in preventing common hypoglycemic symptoms such as headaches, lightheadedness, nausea, and muscular fatigue while also delivering a preferred fuel source which can be rapidly oxidized in favor of limited glycogen stores located in the liver and muscle. This feeding strategy has been shown in a number of studies and recent reviews to minimally maintain and likely have ergogenic benefits [1,3,8,26]. Finally, and while most of this research has used endurance modes of exercise, a number of studies are also available demonstrating that providing a glucose-only beverage or a combination of carbohydrate and protein or amino acids favorably impacts performance, muscle damage, and recovery [27–30].

Carbohydrate Intake into Recovery

The extent to which carbohydrate intake should be considered depends largely upon the duration and intensity of exercise, but an equally important factor is the time available for recovery to take place. A number of strategies including but not limited to the glycemic index of the carbohydrates being consumed, adding protein to carbohydrate, and adding caffeine have been examined for their ability to favorably influence both the rate and extent to which recovery of lost muscle glycogen occurs [3,31,32]. Collectively, these studies indicate that the single most important variable to optimize recovery of lost muscle glycogen is the absolute amount of carbohydrate intake [3,31]. Table 36.2 highlights specific recommendations regarding carbohydrate intake.

Briefly, carbohydrate intake following an exercise bout should begin immediately, to take advantage of favorable hormonal environments upon which timely nutrient administration can both facilitate recovery of lost glycogen and minimize muscle protein breakdown. As duration, intensity, or both increases, carbohydrate intake should also increase. For moderate-intensity exercise lasting 45 minutes to 1 hour, daily carbohydrate intake of 5–7 g kg^{-1} body weight day^{-1} is necessary. For moderate exercise lasting one to three hours, it is recommended that athletes consume 7–10 g kg^{-1} day^{-1}, while exercise lasting 4–5 hours or greater should consume 10–12 or more g kg^{-1} day^{-1} (see Table 36.2). The timing and amounts of carbohydrate ingested take on an even higher level of importance if time is short between the end of the exercise bout and commencement of subsequent bouts: e.g., for extremely long training sessions (4–8 hours) or multiple training sessions or competitions per day [3,26]. Generally speaking, if an exercise bout consists of moderate-intensity exercise spanning 30–45 minutes, carbohydrate replacement should not be a critical consideration.

Low-Carbohydrate High-Protein Diet: Is it a Good Idea for Athletes?

Popularity of higher-protein lower-carbohydrate diets has grown in our society, which can have potentially negative complications for some athletes. Athletes and coaches need to understand the appropriate energy intake for athletes because of the direct relationship it has with sport-specific energy substrate distribution that can help or hurt performance.

As previously mentioned, the current recommendation for carbohydrate intake for endurance and strength athletes is anywhere between 5 and 12 g kg^{-1} day^{-1} depending upon the intensity and duration of exercise. Because endurance athletes, especially, rely on glucose in the form of glycogen as a main energy source during endurance exercise, low blood glucose can cause symptoms such as mental fatigue or muscular fatigue where the athlete feels lethargic or tired, which will dramatically decrease force output as well as decrease the amount of time they can perform exercise. For strength and power athletes, the use of a low-carbohydrate diet will decrease the amount of force that can be exerted per muscle contraction, which can decrease strength performance. Other symptoms include changes in mood, constipation, headache, and dehydration. For a typical non-athlete a minimal intake of 150 grams of carbohydrate is recommended per day, while athletes require much more. If you are an athlete, or a coach with an athlete, who has these symptoms, increasing carbohydrate intake may be advantageous to performance.

PROTEIN

Structure and Function of Proteins

Proteins, carbohydrates, and fats are the three nutrients ingested in the human body that have the potential to produce energy for the body to perform various types of work. Proteins are distinguished from carbohydrates and fats by the presence of an amino or amine ($-NH_2$) group, which creates the framework for how dietary status and protein needs have evolved. While much of the focus for protein, particularly in the context of exercise and performance, seems to center upon muscle protein and its balance, nearly every one of the human body's 100 trillion cells is composed of various proteins. Thus, they are ubiquitous and function in numerous capacities within the physiology and biochemistry of the human body. The current recommended dietary allowance for protein is $0.8\ g\ kg^{-1}\ day^{-1}$ [17].

Essentiality of Amino Acids

Proteins are composed at the individual level of amino acids, and approximately 20 amino acids are used by the body to build proteins. Unlike carbohydrates or fat, no reservoirs of protein exist in the human body, but protein exists throughout the body as pools of amino acids. These pools are in a constant ebb and flow based largely upon physiological supply and demand [33,34]. This ongoing and dynamic state of amino acid movement highlights the importance of dietary intake of protein as well as the concepts of essentiality and protein completeness. Of the 20 amino acids used to build protein, the essential amino acids cannot be produced by the body, which creates an absolute requirement of their intake in the diet. The nonessential amino acids are subsequently considered as such because they can be made in vast amounts inside the human body. Finally, some amino acids are considered to be conditionally essential, which means that in a normal physiological setting, the body is able to produce adequate amounts, but if the body becomes stressed or physiologically challenged, the production rates become inadequate. In this respect, the indispensable or essential amino acids are histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine). Optimization of human performance places a great deal of focus upon the balance of proteins found within skeletal muscle, and it is worth mentioning that studies indicate an absolute requirement exists for the essential amino acids to maximize muscle protein synthesis [35,36].

Protein Type and Quality

A number of protein types exist which are available, and a complete discussion of each is beyond the scope of this chapter. Within the framework of protein requirements, the notion of protein quality and therein protein completeness will be discussed. A number of ways exist for protein quality to be assessed, and the reader is referred to excellent summaries by Phillips [2] and Rodriguez [37]. Briefly, the protein digestibility corrected amino acid scores (PDCAAS) and protein efficiency ratios (PER) are commonly considered methods to assess protein quality. Using these approaches and all other approaches, the milk proteins (whey and casein) are typically rated as one of the highest qualities of proteins available. However, protein sources from egg, beef, poultry, fish, and other dairy sources should still be viewed as excellent sources of protein.

A complete protein is any protein source that provides all of the essential amino acids in both the correct amounts and proportion to stimulate and support the synthesis of new proteins [2]. In this light, incomplete protein sources fail to provide at least one (or more) of the essential amino acids in the correct amount and proportion. Moreover, even protein sources which lack only one amino acid in adequate amounts are viewed to be incomplete (e.g., most versions of soy protein lack adequate required amounts of methionine). For this reason, complete protein sources are considered to be of higher quality, and dietary protein sources of animal origin (e.g., egg, milk or dairy, and flesh proteins such as fish, poultry, beef, pork, bison, etc.) are broadly classified as complete protein sources. Protein sources derived from plants or vegetables are commonly void of one or more of the essential amino acids and must be combined with complementary incomplete protein sources to produce a complete protein.

Protein Requirements of Endurance Athletes

As with other nutrients, "blanket" or "cookie-cutter" recommendations are not appropriate for the dietary protein requirements of endurance athletes. Certainly, the provision of recommendations to multiple athletes lends itself to overgeneralization, but the diligent athlete, coach, or practitioner will closely evaluate and consider other important factors such as training status, exercise intensity, workout duration, gender of the athlete, and dietary energy and carbohydrate intake. In this regard, a prudent approach to recommendations was adopted by Tarnopolsky [38] where he classified athletes as either recreational athletes (those predominantly performing low- to moderate-intensity endurance exercise), modestly trained athletes, and top sport or elite endurance athletes.

For recreational athletes, a number of previously published reports have reached a consensus that this amount and intensity of endurance exercise does not appear to markedly alter the balance of protein or amino acids throughout the body, particularly when energy intake is adequate [6,38–42]. For example, El-Khoury and colleagues determined that a protein intake of $1.0\ g\ kg^{-1}\ day^{-1}$ in young men performing two 90-minute bouts of exercise at 50% VO_{2max} yielded a neutral nitrogen balance [43]. Extensions of this work showed that, when additional protein was provided in the diet, increases in leucine oxidation (an indicator of excess protein intake) occurred [44,45].

The report by Tarnopolsky highlighted three studies which examined protein intake needs of modestly trained endurance athletes [38]. Meredith and investigators had younger (27 years, $VO_{2max} = 65\ mL\ kg^{-1}\ min^{-1}$) and middle-aged men (52 years, $VO_{2max} = 55\ mL\ kg^{-1}\ min^{-1}$) consume three different protein intakes (0.61, 0.92, and $1.21\ g\ kg^{-1}\ day^{-1}$) and reported that a protein intake of $0.94\ g\ kg^{-1}\ day^{-1}$ resulted in a zero net balance of protein [46]. Additionally, Phillips determined nitrogen balance in a group of well-trained men and women who consumed a diet that contained $0.86\ g\ kg^{-1}\ day^{-1}$ protein, which resulted in a net negative balance of protein [47]. Of particular interest, additional analyses revealed that these subjects were in energy balance. Finally, a diet which contained a protein intake of $1.0\ g\ kg^{-1}\ day^{-1}$ was insufficient to prevent a net negative balance of protein [48]. Collectively, it can be concluded that in modestly trained endurance athletes, independent of gender, protein intake ranging from the current recommended daily allowance (RDA) of $0.86\ g\ kg^{-1}\ day^{-1}$ up to $1.0\ g\ kg^{-1}\ day^{-1}$ is inadequate to prevent a net loss of body protein [38].

A small collection of studies has examined the protein requirements and protein metabolism of top sport endurance athletes. Tarnopolsky and colleagues completed a nitrogen balance experiment in six elite male endurance athletes and determined a protein intake of $1.6\ g\ kg^{-1}\ day^{-1}$ was needed [49]. Friedman and Lemon also determined nitrogen balance in a group of five elite endurance runners and concluded a protein intake of $1.49\ g\ kg^{-1}\ day^{-1}$ was advised [50]. A Tour de France simulation by Brouns in well-trained cyclists yielded a protein requirement of $1.5–1.8\ g\ kg^{-1}\ day^{-1}$ [51,52]. Furthermore, a randomized crossover approach using highly trained ($VO_{2max} = 70.6 \pm 0.1\ mL\ kg^{-1}\ min^{-1}$) male endurance runners, where they consumed three diets providing varying amounts of dietary protein (low-protein 0.8, moderate-protein 1.8, high-protein $3.6\ g\ kg^{-1}\ day^{-1}$) determined that nitrogen balance was negative during the low intake of protein and was positive during both the moderate- and high-protein intakes. Additionally, markers of excessive protein intake and oxidation were evident for the high-protein intake. The authors concluded that a protein intake of $1.2\ g\ kg^{-1}\ day^{-1}$ was needed to achieve a positive net protein balance [7].

In summary, the protein needs of endurance-training athletes depend upon many factors, including volume, intensity and duration of training, gender of the athlete, energy and carbohydrate intake, and the current fitness level or training status of the athlete. Of these factors, it is important to highlight the impact of gender on dietary protein needs. In this respect, Tarnopolsky used data from six published reports to clearly highlight that the protein requirements for men are approximately 25% greater than those for women.

It remains that recreational athletes performing low- to moderate-intensity endurance activity do not have increased requirements for dietary protein, whereas modestly trained athletes may have a 25% increase in protein needs (to $\sim 1.1\ g\ kg^{-1}\ day^{-1}$) [38]. Only elite athletes or those with exemplary fitness status and who are performing extremely high volumes of training exhibit markedly increased protein requirements, which amount to approximately $1.6\ g\ kg^{-1}\ day^{-1}$.

Protein Requirements of Strength and Power Athletes

Acute resistance exercise increases rates of both muscle protein synthesis [53–56] and muscle protein breakdown [53–55]. If food intake is absent, net protein balance remains in a negative state [53,54]. While ingestion of carbohydrate helps to attenuate changes in muscle protein breakdown, which improves overall net protein balance [57–59], ingestion of protein and/or amino acids alone or in combination with carbohydrate is required to yield a net positive protein balance [58,60–63]. Increases in lean body mass are the result of chronic resistance training and provision of amino acids and/or protein which results in a robust increase in net protein balance. Additionally, regularly resistance training invokes additional sources of stress and trauma that in turn require greater amino acid/protein availability to repair any ultrastructural damage which may be occurring secondary to the resistance training. This theoretical framework suggests that resistance training athletes would have an increased requirement of dietary protein. Indeed, studies which have directly compared the protein requirements of individuals habitually performing resistance training with those of sedentary individuals indicate that protein needs are in fact greater [49,64,65].

As with endurance training, a number of factors impact protein turnover, but training status appears to greatly impact the efficiency with which the body processes protein [54,66]. For example, untrained or unaccustomed individuals who begin performing resistance training almost universally have been shown to have increased requirements of dietary protein. But as the resistance training becomes habitual, the efficiency with which the body handles or processes its protein stores goes up, and several published reports indicate that more-trained individuals have lesser dietary protein requirements [54,66]. As a result, no consensus exists on whether resistance exercise increases protein requirements, largely because of concerns over which is the best method to assess protein requirements [67].

Tarnopolsky and colleagues estimated the protein requirements for American football and rugby players by comparing protein turnover rates using a combination of nitrogen balance and kinetic measurements after the athletes consumed diets which contained a low, moderate, or high amount of protein: 0.86, 1.4, or 2.4 g kg^{-1} day^{-1}, respectively. The authors concluded that the lowest intake of protein compromised protein synthesis when compared with the diets which provided moderate and high amounts of protein [64]. Other studies which determined dietary protein needs in resistance-trained athletes to be in the range 1.4–1.7 g kg^{-1} day^{-1} [64,65] are commonly reported in the literature to justify increased protein intakes, but criticism regarding utilization of the nitrogen balance approach has precluded full acceptance of these recommendations [67]. While controversy abounds, a well-crafted position statement from the International Society of Sports Nutrition (http://www.sportsnutritionsociety.org), a professional organization devoted to the professional advancement of the field of sport nutrition, recommend protein intakes for resistance-training athletes to be in the range of 1.4–2.0 g kg^{-1} day^{-1} [68], and a recent consensus statement from the American Dietetic Association (http://www.eatright.org), American College of Sports Medicine (http://www.acsm.org), and Dietitians of Canada (http://www.dietitians.ca) recommended a general protein intake of 1.2–1.7 g kg^{-1} day^{-1} [1,17]. Moreover, a regression approach of nitrogen balance data from studies of people who were undergoing regular resistance training was employed by Phillips to determine an optimal daily intake of dietary protein [67]. Using this approach, he concluded that on average these athletes required approximately 49% more protein than the current RDA, or a value of 1.19 g kg^{-1} day^{-1}. When

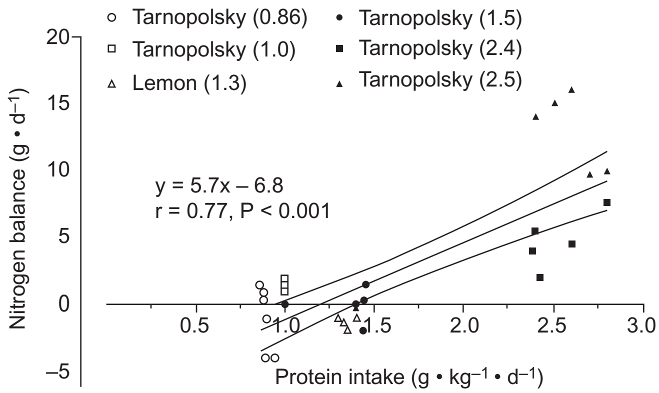

FIGURE 36.1 **A regression approach of nitrogen balance data indicating estimated protein requirements.** *Figure used with permission from Phillips [67].*

a 95% confidence interval was included, a protein intake of 1.33 g kg^{-1} day^{-1} was determined (see Figure 36.1).

In conclusion, optimal protein intake is a key factor to facilitate optimal adaptations and recovery from stressful exercise, regardless of whether it is endurance or resistive in nature. Studies clearly indicate that, when athletes are regularly performing exercise of appropriate intensity, volume and duration, protein needs are increased. The extent to which these values are increased invites controversy, but recent position statements and review papers reveal that a protein intake of 1.2–2.0 g kg^{-1} day^{-1} should more than capture the protein needs of exercising athletes. Outside of these general guidelines, specific considerations should be made after closely assessing key factors such as energy and carbohydrate intake, gender (particularly for endurance athletes), and training status. Finally, analyses of nutritional intakes of athletes routinely and almost unanimously indicate that athletes do an exceptional job of consuming even these greater recommended amounts of protein (see Figure 36.2) [67]. While these data provide sound evidence with which to advise athletes against protein supplementation, other factors such as optimal nutrient timing, and leucine and essential amino acid intake during acute or immediate recovery, will continue to fuel these recommendations.

FATS

Structure and Function of Fats

Dietary lipids are often long hydrocarbon chains, highly insoluble in water and, like carbohydrates, contain carbon, hydrogen and oxygen. Lipids are primarily incorporated into bodily tissues as triglycerides in adipose tissue. Triglycerides consist of two primary components: a glycerol backbone and three fatty acids.

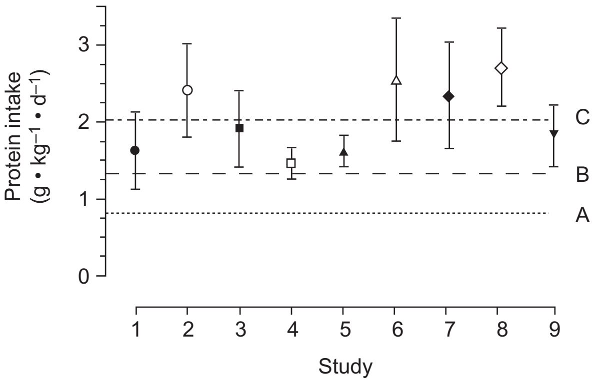

FIGURE 36.2 **Reported habitual protein intakes in resistance-trained athletes.** Line A is current RDA (0.8 g kg^{-1} day^{-1}). Line B is an extrapolated "safe" protein requirement (1.33 g kg^{-1} day^{-1}). Line C is mean reported protein intake (2.05 g kg^{-1} day^{-1}). Values are means ± standard deviation. *Figure adapted from Phillips [67] with permission.*

Glycerol production typically derives through its incorporation into the glycolytic process, where fatty acids can range from short-chains to the most common long-chains, typically 16–20 carbons in length. As nutrients, lipids or fats are the most energy dense and serve primary functions as insulator, energy supply, backbone of cholesterol and fat-soluble vitamins, and key components of cell membranes and nervous tissue. The American Dietetic Association recommends that 30% of total calories come from dietary fat.

Fat Types and Quality

A number of different types of fat exist. The primary means of differentiation is the degree of saturation whereby fully saturated fatty acids contain no double bonds, and mono- and polyunsaturated fatty acids contain one or more than one double bond, respectively. Nutritional epidemiology studies indicate that higher dietary intakes of saturated fatty acids and cholesterol exert negative impacts on cardiovascular health whereas mono- and polyunsaturated fatty acids exert more healthful impacts. Other classes of lipids include the phospholipids, which are incorporated into several different aspects of membrane structures, and the lipoproteins, which are a class of lipids with varying amounts of lipid, cholesterol and protein. Due to their insoluble nature, lipids must be incorporated into lipoproteins to allow for their transport in the highly aqueous medium of the blood. Finally, lipids incorporated into sterols, of which cholesterol and its esters are the most predominant, have central roles in sterol production.

Fat Requirements of Athletes

Increasing the proportion of dietary fat has been a dietary strategy employed by athletes. The rationale for this approach is based primarily upon enhancing endogenous stores of intramuscular triglycerides, which, as the theory goes, should improve prolonged exercise performance while preserving glycogen stores [18]. This theory and approach has been considered by endurance athletes to enhance performance of this type of exercise. In contrast, little consideration of modifying fat intake has been considered by strength and power athletes. While high-fat diets are employed by individuals interested in maximizing leanness as part of the sport of bodybuilding, these considerations lack the necessary relevance to enhancement of sporting performance and for this reason won't be discussed in this chapter. Burke and investigators appeared to offer exciting data after they demonstrated that 5 days of a high-fat (~65% of total calories from fat) and low carbohydrate (2.5 grams carbohydrate per kilogram body mass per day) enhanced fat utilization and still allowed the athletes to complete high-intensity/high-volume training [69]. Further, the increases in fat utilization even persisted after a carbohydrate loading protocol was followed and muscle glycogen levels were replenished. Collectively, this diet manipulation provided indications that high fats followed by a carbohydrate loading could create a favorable scenario where skeletal muscle was able to oxidize more fat while also having a plentiful supply of muscle glycogen. Subsequent research, however, failed to demonstrate increases in exercise performance [70], and in fact rates of muscle glycogen utilization were found to be reduced throughout the exercise bout [71]. When one considers that greater availability of carbohydrate should facilitate enhanced power production and exercise intensity, particularly towards latter periods of a prolonged exercise bout (i.e., the "kick" or "final push"), these findings were considered to be counterproductive.

While a good bit of research has been conducted to examine the efficacy of high-fat diets, a consensus appears to exist that increasing the proportion of dietary fat is not a recommended strategy for enhancement of sport performance. Johnson completed an excellent review of the literature and stated the following regarding the impact of a high-fat diet on physical activity performance: (i) no definitive conclusions can be drawn to indicate that depletion of intramuscular triglycerides negatively impacts performance (one of the underlying theories suggested to improve performance); (ii) high-fat diet consisting of >46% of total calories as fat and <21% of total calories as carbohydrate stimulates fat oxidation through mechanistic adaptations including increased fatty acid oxidation enzymes as well as enhancements of both fatty acid transport and beta-oxidation; and (iii) exercise performance was not improved and in some cases it was negatively impacted [18].

Increasing dietary fat intake has been suggested to favorably impact substrate utilization, but negative performance outcomes and reports of both reduced carbohydrate utilization and gastrointestinal upset have led to the consensus that high-fat diets are not recommended. Irrespective of whether the high intake of dietary fat or the likely concomitant reduction in dietary carbohydrate is responsible for untoward outcomes, the practice of high-fat diets is not advised. A consensus statement by the American College of Sports Medicine, American Dietetic Association, and Dietitians of Canada advise a fat intake of 20−35% of total calories from fat [1,17]. These groups further advised that diets with less than 20% of total calories from fat do not benefit performance, since fat is a source of energy and necessary for production of both fat-soluble vitamins and essential fatty acids.

CONCLUSIONS

Optimal exercise performance is first predicated upon adequate energy intake that will allow for effective delivery of required fuels not only during the energy-demanding exercise period, but also during needed recovery. Ensuring appropriate energy intake is a critical first step for any athlete who desires to achieve optimal performance. Carbohydrates are the preferred, but substantially limited, source of fuel used by nearly every type of athlete who performs at high levels of their ability. Aggressive strategies must be employed to ensure optimal carbohydrate is available. Equally important is meeting the required demands for dietary protein, which facilitates optimal recovery. Dietary needs and requirements for both carbohydrate and protein are increased in nearly every exercising population. Lastly, adequate fat intake is also important and, while fat loading or high-fat diets have proven to be ineffective, a diet which provides 20−30% of its total calories from fat is recommended to ensure optimal fat intake is achieved.

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