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REVIEW

Optimal Protein Intake in Athletes

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ABSTRACT

Optimal protein requirements and supplementation are a topic of great interest for competitive and recreational athletes. However, there is considerable debate as to what constitutes adequate intake in sporting populations. Multiple studies have been undertaken to assess protein utilization and protein supplementation. The current consensus in the literature advocates a diet containing 1.2-1.8 grams of protein per kilogram of body weight per day for strength athletes and 1.2-1.4 grams per kilogram of body weight per day for endurance athletes. Metabolic studies have shown a diet containing 2.4 grams per kilogram to be excessive. The average American diet contains more than 200% of the recommended dietary allowance (RDA), with some athletes consuming diets containing up to 6.4 grams per kilogram of body weight per day. Given a well-balanced, calorically appropriate diet, there is no evidence to support intake above these levels. Furthermore, female athletes in particular must take care to ensure that they receive adequate protein from a balanced diet and be selective about their athletic supplementation.
Keywords: Athlete; Ergogenics; Protein supplementation.

INTRODUCTION

The word *protein* is derived from the Greek meaning "of prime importance." As early as 460 B.C., Dromeus of Stymphalus, a marathoner and trainer at Olympia, endorsed a diet rich in meat for his athletes [1]. Even Pythagoras, a confirmed vegetarian, advised Eurymenes of Samos, a heavyweight fighter, to eat a meat diet [2]. In the early 1800s, it was believed that protein was the major fuel for exercise [3]. It was not until the early 1900s that new evidence supported carbohydrates and fat as the major energy substrates [4]. This evolution in thinking was so complete that despite the tremendous amount of information gathered concerning exercise metabolism, only a small portion deals with the role played by protein [5,6]. This is best illustrated by the fact that the recommended dietary allowance (RDA) for protein of 0.8 g/kg

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has adjustments for pregnant women, the elderly, and infants but not for more active populations, such as athletes. Consequently, the RDA for athletes is much more ambiguous [7-9].

The purpose of this paper is to provide a review of the literature and current recommendations for protein intake in athletic populations.

STUDY DATA

Medline and Google Scholar were searched to locate pertinent studies both historic and recent (within the last 10 years). Additionally, data were acquired from the Centers for Disease Control and Prevention (CDC) and other public sources. Additional emphasis was placed on recent and higher-level studies.

RECOMMENDED DIETARY ALLOWANCE

The RDA is set by the Food and Nutrition Board of the National Research Council/ National Academy of Sciences as the daily average intake of the nutrients of a healthy yet sedentary population over time in order to prevent malnutrition. It is defined by the National Academies as the average daily dietary intake required to meet the needs of nearly all healthy individuals in a certain group and is agreed to be 0.8 g/kg of body mass [10]. This figure is the result of numerous studies using nitrogen balance among other techniques.

The central point inherent to most studies that determine the RDA is that no two individuals have identical physiologies. As such, the RDA is based on linear regression models in which the final recommendation is within two standard deviations of the mean in order to make this group a more representative sample and account for individual variations in, for example, lifestyle, digestibility of dietary protein, and quality of proteins [5]. However, this convention excludes those outside of this range and is not universally accepted. First, the complexities of metabolism and inaccuracies in measurements ensure that the RDA is not a precise measurement, but rather a consensus of research [5]. Second, much of the research that provided the scientific basis for the RDA relied on manifestations of inadequate intake as an indication of the requirement level. This introduces even more uncertainty as many studies do not follow patients long enough for these effects, such as changes in skeletal muscle turnover, to present [11]. Finally, and most importantly, the RDA is based on the assumption that study populations exercised to the same extent as the general population, but no adjustment is suggested for optimum athletic performance. This shortcoming is reflected in the RDA's definition as applying to "individuals in a certain group." For these reasons, it is reasonable to assume that athletes are among those outside of the normal distribution and, as such, the RDA is inadequate as a guideline for an athlete's diet and should be used at best as a minimum requirement.

Historically, Krebs calculated that between 32 and 43 ATP is generated from one mole of amino acid oxidation [12]. Furthermore, several studies have shown that the energy derived from amino acid oxidation increased relative to exercise intensity and was capable of providing up to 10% of the total energy cost [13-16]. Although the contribution of protein to total energy output is small when compared with carbohydrates or fat, it may play a significant role in competitive athletics, in which elite athletes are often very evenly matched [5]. However, protein requirements cannot be considered in isolation as the intake of dietary energy from fat and carbohydrates greatly influences the need for protein and vice versa [7]. This view is backed by Astrand who stated, “Protein is not used as a fuel source at any appreciable extent as long as energy supply is adequate” [17]. Moreover, any experimental dietary changes should allow for a period of adjustment before values stabilize [18]. Additionally, studies by Butterfield, Gontzea, and their colleagues have demonstrated that protein requirements are lower at the end of an experiment than at its onset [19,20]. This implies that in the early phase of training when stress on muscles is highest, protein is used mainly for muscle building but later plays more of a supportive role in supplying energy.

The need for increased protein in athletes is conceptually simple. First, it is important to note that whole body protein includes the globular proteins (eg, hemoglobin, myoglobin, enzymes) as well as the structural proteins (ie, actin, myosin, and troponin). Any increase in the production of these proteins would necessitate an increase in protein availability. Interestingly, the contribution of amino acids to the overall fuel supply in heavy resistance exercise is remarkably small [21]. In fact, the bulk of the protein seems to be used to repair damaged muscle and synthesize additional muscle proteins [22]. Anabolic effects occur with strength training when exercise-induced stimulation of myofibrillar protein synthesis exceeds protein degradation [21]. In contrast, when a muscle works against prolonged moderate resistance, as in endurance exercise, amino acid oxidation is quite significant [1]. Furthermore, endurance training results in increased mitochondrial enzyme synthesis, not myofibrillar protein synthesis [23]. This implies that during endurance exercise, amino acids are being used in an energy-producing role rather than for muscle hypertrophy as is the case in resistance exercise. Since protein synthesis of any kind requires a state of positive nitrogen balance, the protein intake for endurance athletes is just as critical as for strength athletes.

Through linear regression methods, Butterfield et al. [24] concluded that the optimum protein intake for heavy resistance -type athletes should be between 1.7 and 1.8 g/kg/day. However, muscle hypertrophy can occur at protein levels as low as 1.2 g/kg/day [25]. The beneficial effects of increased protein consumption seem to plateau well below the level consumed by many athletes [9]. Tarnopolsky et al. [21] performed a tracer study in which subjects who underwent heavy resistance training on a 1.4 g/kg/day diet were found to have increased levels of protein synthesis as compared with a control group, in whom consumption was 0.9 g/kg/day. However, protein synthesis was not further elevated in the group that consumed 2.4 g/kg/day. More recently, a study was performed in which strength-trained athletes were placed on a low (0.86 g/kg/day), medium (1.4 g/kg/day), or high (2.4 g/kg/day) protein diet and their progress was evaluated. In the low-protein group, protein synthesis slowed. This was not seen in the medium- and high-protein groups. However, in the high-protein group, amino acid oxidation was elevated, indicating excessive intake [22]. Hence, it seems that athletes who engage in heavy-resistance exercises benefit from a diet in excess of the RDA. However, the extent to which this excess is beneficial is minimal as even 2.4 g/kg/day may be excessive [9,21,26]. Additionally, research shows that subjects who strength train regularly adapt to decrease protein turnover, increase retention, and increase the efficiency of amino acid utilization [25,27]. This further emphasizes the point that protein needs will be initially much higher, but as the body's efficiency for protein utilization increases, required protein may decrease [27].

For the endurance athlete, the need for increased protein is not as intuitive. Clearly, the degree of muscle mass development in these athletes is not as dramatic as in the strength athlete. However, protein is important for the endurance athlete. Endurance exercise alters protein metabolism as in resistance exercise. In the endurance athlete, the bulk of protein metabolism is geared toward amino acid metabolism for energy and increased mitochondrial protein synthesis [13,15,23,28,29]. Dietary protein intake in excess of the RDA may be necessary to cover the loss of amino acids due to oxidation and/or to maximize these training adaptations [9,16].

While most agree that the stored phosphagens (ATP and creatine phosphate) are the most readily accessible energy source and the greatest source of stored energy, the role of protein is often overlooked [5]. The alanine cycle, for example, is an essential pathway in which alanine serves as an intermediate in energy production as the amino acids present in skeletal muscle are used in gluconeogenesis [30]. Alanine output from exercising muscle increases at a rate proportional to exercise intensity [31,32]. Branched-chain ketoacid dehydrogenase, another enzyme involved in gluconeogenesis, is also activated proportionally to exercise intensity. The rate of leucine oxidation can be increased to up to six times the resting rate during exercise [8]. These data support the premise that exercise on a regular basis increases amino acid utilization and, thus, daily dietary requirements.

Although studies have supported that the rate of amino acid oxidation is proportional to exercise intensity, it also seems to be dependent upon exercise duration [13,33,34]. Excretion of urinary 3-methyl-histidine and urea (amino acid metabolism by-products) increases with prolonged endurance exercise [8,21,35,36]. This is postulated to be an effect of carbohydrate depletion [37]. The literature supports endurance athletes' consuming between 1.2 and 1.4 g/kg/day or 150% to 175% of the RDA [38-42]. It is important to note that these studies were performed using male athletes and the results may not be reproducible in females as some studies suggest that women utilize less protein than men when performing endurance exercise [21,43,44].

The newest clinical guidelines regarding the recommended daily protein intakes for athletes suggest a range of 1.2 to 1.4 grams of protein per kilogram for endurance athletes and 1.2 to 1.7 grams per kilogram for strength athletes [45]. The guidelines' emphasis on a range rather than a single number to account for individual differences in chemistry and exercise type (strength vs endurance) is upheld. The National Athletic Trainers' Association's recommendations adopt a "food first" philosophy in which it is stressed that trainers and other professionals should assess an athlete's nutrition status and assess for any required changes in diet before any other adjustments are made [46]. Additionally, Tipton [25] has pointed out that if an athlete is to increase protein intake but maintain constant calories, he or she must decrease intake of fat or carbohydrates. Tipton stresses the importance of carbohydrates for fueling exercise and notes that decreasing them may inhibit optimal performance [25].

Studies assessing protein requirements rely on nitrogen balance, urinary excretion of urea, N-methylhistidine, and metabolic tracers [5,6,30]. Positive nitrogen balance is essential for hypertrophy and requires the athlete to consume more protein, which is nearly 16% nitrogen, than is utilized [5]. Nitrogen balance confounders, such as nitrogen losses in sweat, must be considered [47]. In fact, at a given protein intake, increased net dietary energy consumption can cause nitrogen balance to become more positive [19,26]. As such, it is essential to consider both the muscle-building and caloric utility of protein as well as the importance of obtaining protein as part of a well-balanced diet. Gontzea & Jantea placed two groups on diets containing 125% and 188% of the RDA of protein [38]. At the onset of daily endurance training, it was observed that the nitrogen balance of both groups decreased and in fact became negative in the 125% group even though total dietary energy intake increased during the study. Nitrogen balance was less negative toward the end of the experiment in both groups, demonstrating that in untrained subjects, protein requirements are more important at the beginning of an exercise program, when muscle hypertrophy is more substantial [20]. Protein requirements may decrease over time in experienced strength athletes as a result of increased efficiency of protein utilization [45]. Strength trainers assigned a program of 2.4 g/kg/day against a control of 0.8 g/kg/day on a similar strength program for 28 days. A 2.4 g/kg/day protein diet correlated with an increase in nitrogen balance of 12-20 g/day, which would equate to nearly 0.5 kg/day of lean muscle mass acquisition. However, both groups showed similar muscle gains [21,48].

In contrast, a study of elite Polish weightlifters by Celejowa & Homa found that 50% of the athletes were in negative nitrogen balance despite consuming 250% of the RDA for protein [47]. Similarly, in a study of elite Romanian weightlifters, dramatic gains in muscle mass and strength were reported when dietary protein intake was increased from 225% to 438% of the RDA [49]. It must be pointed out that these subjects were in a period of general training. One must take into account individual variations in diet and exercise intensity for these results to be extrapolated to other athletes. A recent meta-analysis found that 1.33 g/kg/day is enough to keep a strength athlete in nitrogen balance. Estimates for endurance athletes were less specific at 1.2 g/kg/day with the possibility of up to 1.6 g/kg/day depending on training specifics [50]. The inherent difficulty in assessing nitrogen balance and in classifying athletes as exclusively strength based or endurance led the American College of Sports Medicine to suggest an alternative to an RDA based solely on weight. Recent guidelines suggest that 10% to 35% of total calories should come from protein. Compliance with a protein requirement relative to total caloric intake accounts for many of the inaccuracies inherent to less flexible recommendations [45].

In addition to the amount of protein, the timing of post-exercise protein consumption is a subject that has received attention.

There is literature to support the benefits of complex protein consumption within 30 minutes of exercise for recovery [51,52]. A recent meta-analysis supports consuming adequate protein in combination with resistance exercise as the key factors for maximizing muscle protein accretion [53]. Additionally, it has been found that the anabolic response following protein consumption lasts around 4 hours. As such, 4-5 meals per day spaced at that interval may be the most efficient intake schedule [50].

Many athletes who attempt to ensure that they ingest sufficient macronutrients to support muscle hypertrophy and repair tend to overconsume protein. This practice, however, has raised concerns regarding the potential health effects of high-protein diets. Hydration, for example, is a key concern for all athletes and a factor that must be considered when discussing protein intake. Protein metabolism and nitrogen excretion require water, and dehydration is imminent if fluids are not well maintained [9,54]. When combined with the water losses of the athlete due to sweat, the urinary water losses from a high-protein diet can potentially be dangerous. However, no relationship between levels of protein intake and progressive decline of renal function has been demonstrated. In fact, high-protein diets may protect renal function [50]. Hence, fluid replacement is a critical concern for any athlete, but the idea that high dietary protein intakes exacerbate this problem or cause renal damage has not been definitively determined.

Contribution of high-protein diets to increased urinary calcium excretion may be a source of additional concern for athletes (55). This is especially the case in females if they suffer decreased bone density due to the female athlete triad (eating disorder, amenorrhea, osteoporosis) [55]. The concern for calciuria should be highest in patients who consume large amounts of purified proteins owing to the relatively high phosphate levels in a diet of this kind [56,57]. The practice of ingesting purified protein among strength athletes is thought to be a reflection of the concern that traditional high-protein diets may be atherogenic (as a result of relying heavily on meats) [51]. However, while increased protein intake does increase calciuria, other compensatory mechanisms yield an increase in bone mineral density [58]. Specific mechanisms may include increased intestinal absorption of calcium, increased IGF-1 release (a main signal for bone health), parathyroid hormone inhibition, and increased muscle strength supporting the underlying skeleton. This protective effect of protein on bone is, however, thought to exist only in the setting of adequate calcium intake [58].

Supplementation of individual amino acids in large quantities such as the branched-chain amino acids (BCAAs) has recently become more common. Leucine in particular has been marketed as a trigger for post-exercise muscle synthesis [9,22]. However, complications such as gastrointestinal absorption disturbances are possible as the gastrointestinal tract more easily accepts dietary proteins when they are complexed as di- and tripeptide molecules [30]. If enough individual amino acids are ingested, the increase in osmolarity could induce diarrhea, electrolyte disturbances, and dehydration. Other potential complications of individual amino acid supplementation include neurotransmitter imbalances, metabolic imbalances, and even toxicity [57,59-61].

Advocacy by team physicians, coaches, and trainers of increasing protein intake without the suggestion that it come in the form of a balanced diet is an additional issue. Especially for women in sports in which the female athlete triad is more prevalent (ballet, gymnastics, and body building), the message should be geared more toward proper dietary techniques rather than supplementation alone. Furthermore, in light of the protein-calorie relationship, in women who consume too few calories the increased protein would be utilized for energy and not for protein synthesis.

One circumstance in which dramatically increased protein intake does seem to make sense is in maintenance of fat-free muscle mass during a caloric deficit. This situation could potentially pertain to forward-deployed, active-duty military members and the athletes competing in weight-based sports. During hypocaloric diets, increased protein intake can make nitrogen balance less negative [62]. In fact, in a recent study, subjects with higher protein intake lost considerably less lean body mass when on a diet containing 60% of their usual caloric intake. However, athletic performance does not seem to be affected by the change in protein intake in the short term [62]. Additionally, fat-free mass and positive nitrogen balance were better maintained in soldiers during exercise-induced energy deficits when protein intake doubled from 0.9 to 1.8 g/kg [63]. A recent systematic review determined that the optimal protein intake to maintain muscle mass during caloric restriction was 2.3-3.1 g/kg, with the caveat that the athlete's body composition prior to the energy deficit be considered [64]. These data seem to support the conclusion that in the case of athletes or soldiers in a hypocaloric state, protein intake above the RDA and as high as 2.3-3.1 g/kg may prevent lean body mass loss.

CONCLUSIONS

Optimum protein synthesis is important for all athletes. The most recent recommendations advocate a diet containing 1.2-1.8 g/kg/day for strength athletes and 1.2-1.4 g/kg/day for endurance athletes. Alternatively, it has been recommended that 10% to 35% of total caloric intake be protein derived. However, the average adult American's diet contains more than 200% of the RDA, with many athletes consuming much more. In spite of the National Athletic Trainers' Association's "food first" policy, this level of protein ingestion is often accomplished partly through supplementation and, whereas modern research has largely absolved high-protein diets of negatively affecting renal function or bone health, this excess consumption is both costly and without proven benefit. Therefore, it is recommended that athletes obtain protein through a well-balanced, calorically appropriate diet and proper hydration while complying with the above protein ranges. Clearly, additional research is required to delineate further what constitutes adequate protein intake in the athletic setting of high energy expenditure and protein utilization.

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