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Review

Dietary protein requirements in athletes

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Current dietary protein requirements were determined using essentially sedentary individuals and, therefore, are designed for the general population. Unfortunately, the recommendations from these studies have been applied to athletes as well. Because of the vast differences in daily energy expenditure alone this would seem to be a naive approach. Moreover in recent years, considerable evidence has accumulated on athletes, primarily those involved at each end of the exercise intensity–duration continuum, i.e., strength (weight lifting) to endurance (running, cycling, or swimming), suggesting that dietary protein needs may be greater by as much as 125% in comparison to sedentary individuals. The additional protein may be necessary for use as an auxiliary fuel for endurance exercise and as a supplementary source of amino acids to build and/or maintain the large muscle mass present in those who strength train. In addition, although more speculative, it is possible that other constituents in high quality protein sources, i.e., creatine, conjugated linoleic acid, carnosine, etc. may also be beneficial. Definitive dietary recommendations for various athletic populations must await further study, but the mass of current evidence indicates that individuals involved in strength/power/speed activities may benefit from intakes of about 1.7 to 1.8 g protein $\cdot$ *g body mass*$^{-1}$ $\cdot$ *day*$^{-1}$ *(approximately 112–125% higher than the sedentary recommendation) and those who participate in endurance activities from about 1.2–1.4 g* $\cdot$ *kg*$^{-1}$ $\cdot$ *d*$^{-1}$ *(approximately 50 to 75% higher than the sedentary recommendation). Assuming total energy intake is sufficient to cover expenditure, these intakes can be obtained from a diet consisting of about 10% energy intake as protein. Some athletes may not consume this amount of protein, especially those who consume inadequate energy (dieters or those trying to maintain an arbitrary body mass for their activity, i.e., gymnasts, dancers, wrestlers, etc.), those who are growing (children, adolescents, women who are pregnant), or those who select diets which may exclude high quality protein sources (vegetarians and seniors). Despite the common practice of consuming greater amounts of protein (2–4 g* $\cdot$ *kg*$^{-1}$ $\cdot$ *d*$^{-1}$*) among strength athletes in particular, few data exist suggesting that this has any further benefit, i.e., there appears to be a ceiling effect. Finally, the concerns expressed routinely about liver or kidney problems with high protein diets have little scientific support; however, the easy accessibility of individual amino acid supplements poses a potentially serious threat because there are likely a variety of confounding interactions and the effects of mega doses of single amino acids are largely untested. Future studies are needed to fine tune these recommendations.* (J. Nutr. Biochem. 8:52–60, 1997.) © *Elsevier Science Inc. 1997*

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Introduction

Based on hearsay and/or trial and error self experimentation many athletes (especially strength athletes) are firmly convinced that high protein diets are advantageous. In contrast, based on the guidelines established by the U.S. Food and Nutrition Board[1] many nutritionists believe that protein needs of athletes are not substantially different from sedentary individuals. Which group is correct? Unfortunately, the rationale behind both views is flawed and there is, as yet, no definitive answer to this question. Clearly, the athletes' stance lacks objectivity, but it may actually be more systematic than the view of the nutritionists who have tradi-

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tionally focused on studies involving essentially sedentary subjects.[1] More than 70 years ago Cathcart[2] concluded that "muscle activity does increase, if only in small degree, the metabolism of protein" but for most of the next 45 years the study of exercise effects on protein need was largely overlooked as scientists concentrated on carbohydrate and fat metabolism.[3–5] As a result, the current recommended dietary allowance (RDA) for protein[1] does not include an additional allowance for those who regularly engage in physical exercise. The purpose of this paper is to provide an overview of some of the available information obtained from the study of rigorous acute exercise and/or exercise training in an attempt to assess whether the current RDA needs to be modified for athletes.

Overview of protein metabolism

Critical to an understanding of the effects of strenuous, chronic physical exercise on dietary protein needs is a working knowledge of how protein is metabolized (*Figure 1*). Briefly, the component parts of protein (amino acids) enter the body's free amino acid pool (body fluids and tissues) from the protein foods we ingest, from the breakdown of body protein, and/or as dispensable (nonessential) amino acids synthesized from a carbon source (carbohydrate or fat) and ammonia. In the nongrowing human an equilibrium exists such that the body protein that is continually being broken down is replaced by protein synthesized from amino acids available in the free pool. However, if dietary protein is less than adequate there are insufficient amino acids entering the free pool to maintain a rate of protein synthesis to counteract protein degradation. This can lead to losses in both muscle size and strength and, as a result, decreased physical performance. If prolonged, overall health could also be negatively affected especially via adverse effects on immune function.[6,7] In contrast, when protein intake is excessive the surplus amino acid carbon is oxidized and/or converted to carbohydrate or fat and stored while the surplus nitrogen is largely excreted (primarily as urea in the urine).

Recent data indicate that regular, strenuous exercise (training) causes significant changes in protein metabolism.[8] For example, if a muscle contracts intermittently against a significant overload (typically referred to as heavy resistance or strength exercise) protein synthesis is enhanced for at least 24 hr post exercise[9] and, as a result, with time the muscles involved get bigger and stronger (*Figure 2*). Despite the intense nature of strength exercise amino acids appear to contribute insignificantly to fuel supply.[10] In contrast, when a muscle contracts on a regular basis rhythmically against a more moderate load over a prolonged time period (typically referred to as endurance exercise) an increase in mitochondrial (enzymatic) not myofibrillar protein synthesis occurs.[11] This results in a reduced reliance on carbohydrate and increased fat metabolism at the same exercise workload.[12] Moreover, during this type of exercise, the total quantity of amino acids oxidized can become significant.[13–17]

Traditionally, protein metabolism has been assessed by measurements of nitrogen balance (difference between nitrogen intake and excretion).[1] Whenever intake exceeds excretion protein is being retained by the body. This situation is necessary for growth and is generally referred to as positive nitrogen balance (although positive nitrogen status is probably a better term). Conversely, if excretion exceeds intake a negative nitrogen balance (status) exists and body tissue is being lost. Although a classic method, the nitrogen balance (status) procedure is somewhat limited because it is very labor intensive and it cannot detect changes in the various component processes (oxidation, synthesis, degradation—right side of *Figure 1*) of protein metabolism.

More recently, metabolic tracers, i.e., radio- or stable labeled isotopes (^{14}C, ^{13}C, ^{15}N, etc.) have been used to assess changes in protein status. This technique makes it possible to

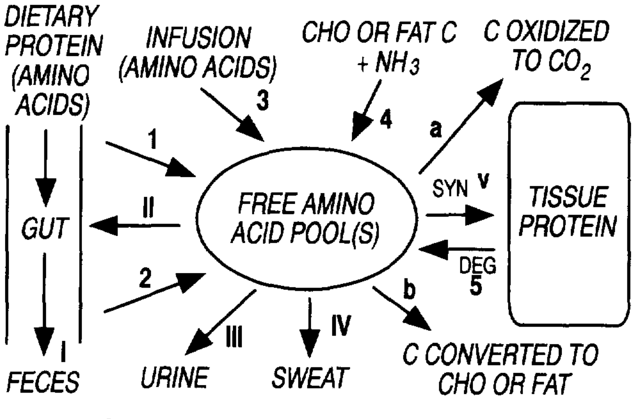

Figure 1 Schematic representation of how protein is metabolized. Amino acids enter the body's free amino acid pool (through which all amino acids must pass) a number of ways (arabic numbers), whereas amino nitrogen (Roman numerals) and amino carbon (letters) exit the free pool through several routes. The classic nitrogen balance (status) technique considers net nitrogen status (intake – excretion) only. The metabolic tracer technique enables investigators to assess the component parts of protein metabolism (oxidation, protein synthesis, and protein degradation) (adapted from Ref. 96).

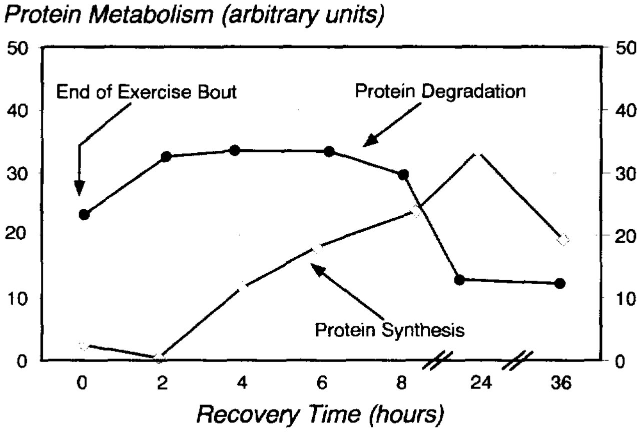

Figure 2 Schematic representation of how protein metabolism is altered after a bout of physical exercise. The time course varies with exercise type (strength versus endurance), but if sufficient recovery occurs between training bouts, i.e., if overtraining is avoided, protein synthesis exceeds degradation resulting in increased muscle protein. The units for protein metabolism (*y* axis) are arbitrary (adapted from Ref. 95).

investigate the various components of protein metabolism.[18,19] However, tracer methodology also has several drawbacks including expense, degree of invasiveness, and whether the various assumptions on which it depends are valid.[19–21]

Effects of endurance exercise on protein requirements

If one looks at the exercise literature carefully, several fascinating observations can be found during the 1970s that provide clues that exercise has much more dramatic effects on protein metabolism than was believed at the time. For example, during endurance exercise output of the amino acid alanine from exercising leg muscle (*Figure 3*) increases substantially in an exercise intensity-dependent manner.[22] This important finding led to our understanding that alanine is synthesized in exercising muscle using glucose-derived pyruvate carbon and nitrogen from a select group of amino acids called the branched-chain amino acids (leucine, isoleucine, and valine). This helps reduce muscle pyruvate accumulation and, therefore, lactate production, which is a major factor in exercise fatigue.

Several laboratories became interested in determining the ultimate fate of the carbon from these amino acids and observed significant increases in amino acid oxidation with moderate and high intensity exercise.[13–17,23] Further increases have been found with endurance exercise training.[24–26] Therefore, the branched chain amino acids may provide a significant source of auxiliary fuel for endurance exercise. Others noted increased production and/or excretion of the major end-product of amino acid oxidation (urea) with prolonged exercise[27–30] where glycogen stores are limiting, which led to the understanding that glycogen availability (*Figure 4*) was a regulatory factor in exercise protein use.[29] These results produced a series of further studies (using metabolic traces in addition to the traditional nitrogen balance (status) technique), which revealed consistent data[31–35] indicating that the protein requirement (i.e., amount of protein necessary to elicit nitrogen balance) was indeed greater in endurance athletes (*Figure 5*). As a result, recommendations (i.e., requirement + 2 standard deviations) for protein intake of about 1.2 to 1.4 g • kg body mass^{-1} • day^{-1} for endurance athletes have been proposed.[8,36] Moreover, the energy expenditures of many endurance athletes can become so high that it is difficult to consume enough food to avoid a negative energy balance. In this situation, dietary protein needs are further elevated.[37,38] Therefore, it is important to monitor both energy and protein intake in endurance athletes.

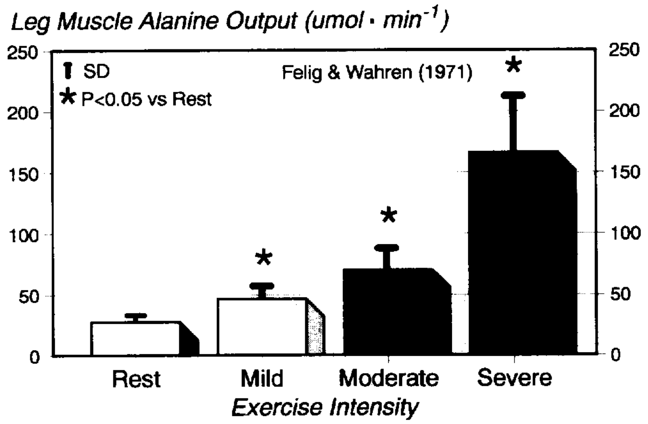

Figure 3 Effect of endurance (40 min duration) exercise intensity on release of the amino acid alanine from exercising leg muscles. Note the large increase especially with high exercise intensity (adapted from Ref. 22).

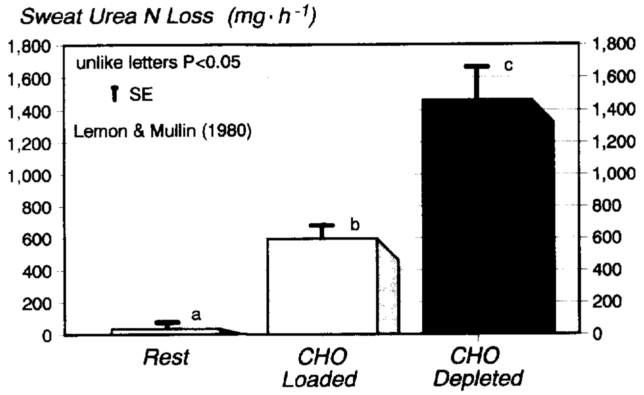

Figure 4 Effect of reduced carbohydrate availability (via prior exercise and diet) on sweat loss of urea (major end product of amino acid oxidation) during endurance exercise (60 min at 61% of maximal oxygen uptake). Note the increase with exercise and the further large increase (>2 fold) with exercise when carbohydrate (CHO) is depleted before exercise (adapted from Ref. 29).

Oxidation of the amino acid leucine may be as high as 86% of the daily requirement even with a relatively mild workout (2 hr at 55% VO_{2max}) for an endurance athlete.[16] The mechanism underlying this response appears to be the exercise intensity-dependent activation of the limiting enzyme (branched-chain oxoacid dehydrogenase; *Figure 6*) in the pathway.[39,40] Moreover, both fasting and high protein diets further elevate branched-chain amino acid oxidation with endurance exercise[41,42] suggesting that branched-chain amino acid availability is also a regulatory factor.

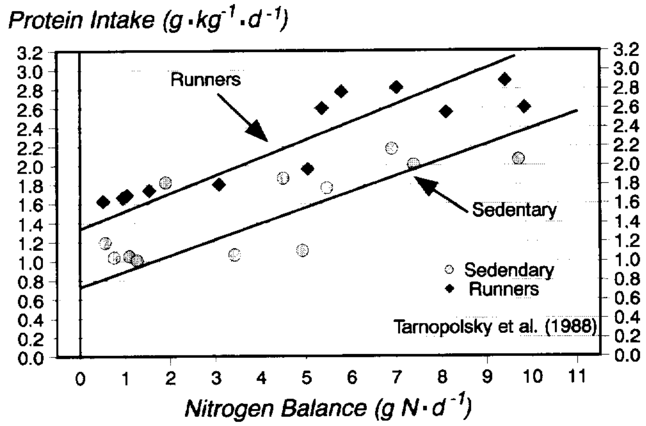

Figure 5 Dietary protein intake versus nitrogen balance in endurance runners during routine training (125 km • wk^{-1}) and in sedentary controls. Note the regression lines are nearly parallel but the line for the athletes is upward and to the left indicating that a greater protein intake is necessary to attain nitrogen balance (1.37 vs 0.73 g • kg^{-1} • d^{-1}, respectively) (adapted from Ref. 35).

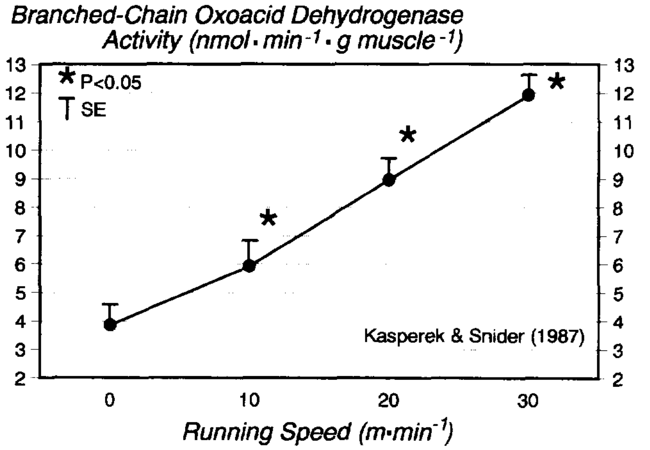

Figure 6 Effect of intensity of endurance exercise (120 min) on activation of branched-chain oxoacid dehydrogenase (limiting enzyme in the branched-chain amino acid pathway). Note the observed increases were 76, 172, and 245% at 10, 20, and 30 $m \cdot min^{-1}$, respectively (adapted from Ref. 39).

To date, only a few amino acids have been studied but it appears that exercise oxidation rates among individual amino acids may vary.[43] As a result, systematic future study is needed to assess whether the apparent increased protein need of endurance athletes could be met by increased intake of a few select amino acids. Although nitrogen balance (status) studies have been the traditional method used to make these determinations, Young et al.[18] have made a compelling argument for the use of oxidative and nonoxidative removal (protein synthesis) measures to assess amino acid requirements. Unfortunately, most of the studies completed so far have used young male subjects and few have attempted to document exercise performance effects. As a result, the effect (if any) of insufficient protein intake on athletic success remains unclear. Future investigations should focus on other populations especially those which are potentially at higher risk. Interestingly, there are some data (*Figure 7*) suggesting that females may utilize less protein with endurance exercise than do males.[44–46] Finally, although there are few studies on active elderly subjects, some recent data suggest that protein requirements are higher in the elderly[47–49] and, therefore, the protein needs of senior athletes may be even greater.

Effects of strength exercise on protein requirements

Clearly regular strength exercise stimulates muscle growth[50] apparently as a result of greater exercise-induced increases in protein synthesis than in protein degradation.[51] Assuming that amino acid supply is the limiting factor in protein synthesis, increased dietary protein could potentiate the enhanced protein synthetic rate that results from this type of training.[36] Whether this actually occurs is of critical importance because, in addition to the benefit this information would have for athletes, the implications are even more significant for several other populations where muscle atrophy is a concern, e.g., inactivity/aging, space flight, muscle injury/disease, etc. Based on the diets of many athletes, it is apparent this group believes that a high-protein intake is critical. Despite the obvious ability of some athletes to develop a huge muscle mass, the fact remains that the evidence on which this opinion is based is largely anecdotal. Obviously, this information alone is insufficient to make a definitive conclusion about whether increased dietary protein is necessary to maximize muscle development.

Several recent studies indicate that a dietary protein intake in excess of the current RDA is likely needed for optimal muscle growth.[2,5,8,36,37,42,52–55] However, as discussed below, the protein synthetic benefit likely plateaus at intakes well below the huge intakes typically consumed by strength athletes. For example,[56] over 4 weeks of heavy resistance-training young adult men consuming 3.3 versus 1.3 g of protein $\cdot kg^{-1} \cdot d^{-1}$ experienced greater body mass gains (*Figure 8*). Similarly, Meredith et al.[57] reported that a daily dietary supplement containing 23 g protein produced greater muscle mass gains with heavy resistance training than training alone. These studies provide objective support that increased dietary protein combined with strength exer-

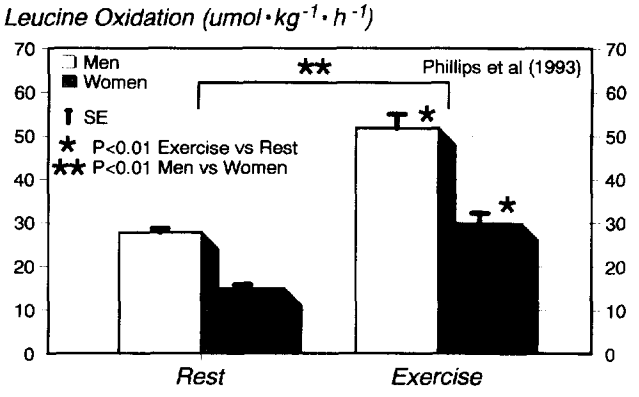

Figure 7 Gender differences in oxidation of the amino acid leucine during endurance exercise (90 min of running at 65% of maximal oxygen uptake). Note that leucine oxidation increased ($P < 0.01$) with exercise in both men and women and that under both rest and exercise conditions the rate was greater in the men (adapted from Ref. 46).

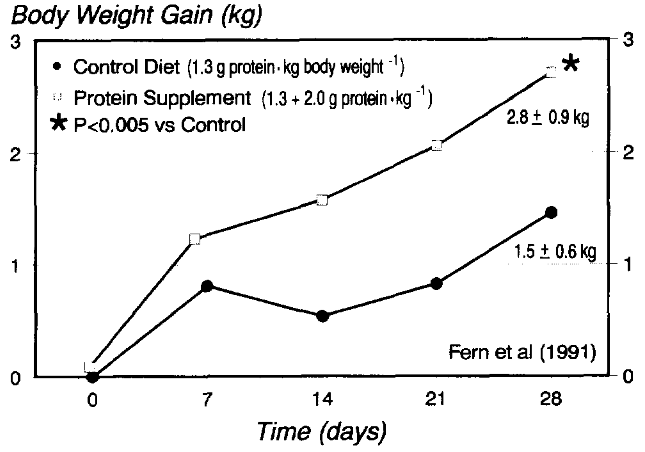

Figure 8 Effect of increasing dietary protein (3.3 versus 1.3 $g \cdot kg^{-1} \cdot d^{-1}$) on body mass gains with 4 weeks of strength training. Note the greater increase ($P < 0.05$) in body mass in the group with the higher protein intake (adapted from Ref. 55).

cise can enhance muscle development relative to training alone.

In addition, at least two other recent studies have observed a negative nitrogen balance (status) in young male strength athletes consuming dietary protein at the RDA.[58,59] These data further suggest that a regular strength training program increases protein needs. Using linear regression methodology (dietary protein versus nitrogen balance; *Figure 9*) these studies concluded that the recommended protein intake for strength athletes should be about 1.7 and 1.8 $g \cdot kg^{-1} \cdot d^{-1}$, respectively. This intake is 212 to 225% of the current RDA.

Two of these studies also assessed changes in protein metabolism using the metabolic tracer technique. For example, in the Fern et al.[56] study (discussed above) the subjects consumed differing quantities of protein (3.3 versus 1.3 $g \cdot kg^{-1} \cdot d^{-1}$) and a greater increase in whole body protein synthesis was observed with the higher protein intake (consistent with the greater gain in body mass); however, there was also a 150% increase in amino acid oxidation. This large increase in oxidative removal indicates that the optimum protein intake had been exceeded. Tarnopolsky et al.[59] also assessed protein requirements with strength exercise using the tracer technique and found that protein synthetic rate was enhanced in strength trainers when dietary protein increased from 0.9 to 1.4 $g \cdot kg^{-1} \cdot d^{-1}$ but, interestingly, was not further elevated when protein intake was increased to 2.4 $g \cdot kg^{-1} \cdot d^{-1}$ (*Figure 10*). In agreement with Fern et al.,[56] these results indicate that individuals who engage in strength exercise will benefit from protein intakes in excess of the current RDA. Moreover, because protein synthetic rate had plateaued and amino acid oxidation increased substantially with the highest protein diet, they further indicate that 2.4 g protein $\cdot kg^{-1} \cdot d^{-1}$ is excessive for strength athletes. In this investigation, sedentary controls were also studied and dietary protein above the RDA had no effect on protein synthesis but relative to the 0.9 $g \cdot kg^{-1} \cdot d^{-1}$ intake, amino acid oxidation increased, not only at the 2.4 $g \cdot kg^{-1} \cdot d^{-1}$ intake, as was observed with the strength athletes, but also with the 1.4 $g \cdot kg^{-1} \cdot d^{-1}$ diet. The fact that the sedentary subjects responded with increased oxidative removal at 1.4 $g \cdot kg^{-1} \cdot d^{-1}$, whereas the strength athletes did not until 2.4 $g \cdot kg^{-1} \cdot d^{-1}$ indicates that protein requirements differ between these two populations.

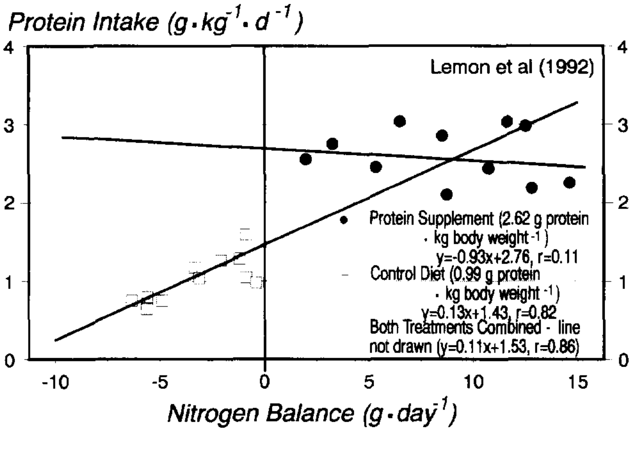

Figure 9 Dietary protein intake versus nitrogen balance of novice strength athletes during routine training (6 $d \cdot wk^{-1}$, 75 min $\cdot$ $session^{-1}$, 3 day split routine). Note that while a strong linear relationship ($r = 0.82$, $P < 0.001$) between protein intake and nitrogen balance (status) was observed at a protein intake around 1 $g \cdot kg^{-1} \cdot d^{-1}$ (protein intake necessary for nitrogen balance = 1.43 $g \cdot kg^{-1} \cdot d^{-1}$) this relationship disappeared with a protein intake between 2–3 $g \cdot kg^{-1} \cdot d^{-1}$ (adapted from Ref. 57).

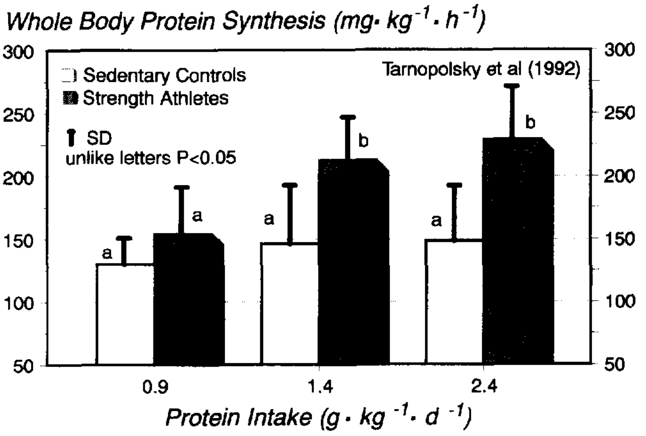

Figure 10 Effect of increasing protein intake (0.9 versus 1.4 vs. 2.4 $g \cdot kg^{-1} \cdot d^{-1}$) on whole body protein synthesis using L-[1-^{13}C] leucine infusion in strength athletes and sedentary controls. Note protein synthetic rate increased ($P < 0.05$) in the strength athletes when dietary protein intake increased from 0.9 to 1.4 $g \cdot kg^{-1} \cdot d^{-1}$ but no further increase was observed with 2.4 $g \cdot kg^{-1} \cdot d^{-1}$ and that protein intake above 0.9 $g \cdot kg^{-1} \cdot d^{-1}$ had no effect on protein synthesis in the sedentary controls (adapted from Ref. 58).

Together, these studies provide evidence that protein requirements are greater in strength athletes than in their less physically active counterparts. Further, they suggest that protein intakes in excess of the RDA can enhance muscle development when combined with regular strength training exercise. Definitive recommendations are difficult but based on both the nitrogen balance (status) and the metabolic tracer data it appears that a protein intake of about 1.7 to 1.8 $g \cdot kg^{-1} \cdot d^{-1}$ (212–225% of the current RDA) may be optimal for this group. It should be understood however, that despite this increased requirement, special supplementation is unnecessary as this quantity of protein can be obtained in a normal mixed diet assuming adequate energy is consumed, e.g., a 21,000 kJ (5000 kcal) diet containing 10% protein would provide about 126 g of protein (1.8 $g \cdot kg^{-1} \cdot d^{-1}$ for a 70 kg individual). Finally, it is very important to note that, at least in drug free athletes, there is little good evidence that the very high protein intakes (>2 $g \cdot kg^{-1} \cdot d^{-1}$) typically consumed by strength athletes are beneficial. Whether greater protein intakes can potentiate muscle growth in strength athletes taking other anabolic agents has not been adequately addressed although clearly some pharmacologic treatments do enhance muscle development.[60]

Recently, there has been an interesting debate about whether dietary creatine (a nitrogen-containing compound found primarily in meat and fish) supplementation can enhance short-term intense exercise performance by increasing muscle phosphocreatine concentration.[61–64] Typically, a dosage of creatine of about 20 $g \cdot d^{-1}$ will increase body mass by about 1 kg over 3 to 5 days. Such a rapid gain is likely primarily water and, if muscle water is increased this could stimulate protein synthesis,[65] leading to an increase in myofibrillar protein with time, especially if combined with chronic strength exercise. Moreover, other potential mechanisms whereby creatine might enhance protein synthesis have been proposed including a direct effect on protein synthesis[66] or an indirect effect via increased phosphocreatine availability.[67] This may mean that the anecdotal experiences of strength athletes (muscle size or strength benefits) are caused by constituents of high protein diets other than total amino acid supply. This possibility is especially intriguing because the role of other components of meat/fish/dairy products such as conjugated linoleic acid,[68,69] carnosine,[70,71] or some other as yet unidentified compound may be important factors in the control of muscle metabolism in vivo.

Adverse effects of high protein diets

It is generally understood that high protein intakes should be avoided because they can be hazardous; however, the potential adverse effects appear to have been overemphasized. For example, potential kidney problems have been extrapolated from studies on individuals with impaired kidney function.[72] Actually, although high protein intakes do place an additional workload on the kidney (due to the increased nitrogen load), this seems to be well within the capacity of the healthy kidney. If high protein diets are a serious concern in healthy individuals it is unclear why a high incidence of kidney problems is not found in middle aged strength athletes as many of these individuals have consumed these types of diets regularly for years. Further, studies on animals with extremely high protein intakes (up to 80% protein) for more than half their lifespan have not revealed any serious adverse effects.[73]

Some data suggest that high protein diets lead to increased urinary calcium loss,[74] which could be hazardous, especially for females because of its involvement with bone health. Fortunately, this adverse effect is likely only a problem with high intakes of purified protein because the high phosphate content of food protein appears to negate this effect.[75] Although adequate protein to maximize muscle development can be obtained in food, those who choose to consume a purified protein supplement might be wise to monitor calcium balance as a precaution.

High protein diets are often considered to be atherogenic because of the associated fat intake.[76] However, these concerns may also have been overstated because 1) the strong association between animal protein and plasma cholesterol observed in animal studies does not appear to apply to humans,[77] 2) the fate of ingested fat for athletes is clearly different than in sedentary individuals,[78] and 3) the relationship between dietary fat and blood fats is apparently not as strong as previously thought.[79,80]

Of some concern is the increased water loss (dehydration) associated with urinary excretion of the additional nitrogen with high protein diets, especially in an athletic population that already has increased fluid needs to compensate for high rates of sweating. This means that fluid replacement must be monitored even more closely when protein intake is high. This is most easily done by regularly monitoring body mass.

Perhaps of greatest concern in the area of protein nutrition for athletes is the intake of large quantities of individual amino acids. This topic is not often considered because it has only been possible in recent years with the commercial development of individual amino acid supplements. Although largely untested, many claims have been made regarding the potential ability of a variety of individual amino acids to enhance exercise performance. At least in theory, several of these could be beneficial;[6,81–91] however, considerable potential also exists for complications including absorption problems, metabolic imbalances, altered neurotransmitter activity, and even toxicity.[92–95] Athletes are particularly vulnerable because they often consider themselves invincible, they are highly motivated to succeed (financial gains are now substantial), and they rarely obtain their nutritional information from qualified individuals. Until more data are available, caution is recommended relative to the use of any of these individual amino acids.

Future directions

Unfortunately, current knowledge of nutritional needs for athletes is extremely limited[1,96,97] because most of the data have been collected using young male subjects (18 to 25 years). Furthermore, although claims of strength gains with high protein intakes are common, few performance studies have actually documented this benefit. Future investigations need to focus on women, other age groups, and groups that may have elevated dietary protein requirements due to coexisting conditions, i.e., growing individuals (children, adolescents, women who are pregnant), and/or those who may not consume an optimal mixture of nutrients (dieters, vegetarians, seniors, etc.). Finally, there needs to be a concentrated effort to document whether the exercise performance benefits typically attributed to high protein diets actually occur.

Summary and conclusions

Despite the fact that most nutritionists believe protein needs are not altered by physical exercise, athletes typically consume protein in excess of the current RDA. Until recently, the opinion of the athletes has been largely unsubstantiated in the scientific literature. However, beginning in the 1970s an increasing number of studies have appeared which indicate that regular strenuous physical exercise can increase dietary protein needs. These data suggest that the RDA for endurance athletes should be about 1.2 to 1.4 g protein $\cdot$ $kg^{-1} \cdot d^{-1}$ (150 to 175% of the current RDA) and 1.7 to 1.8 g protein $\cdot$ $kg^{-1} \cdot d^{-1}$ (212 to 225% of the current RDA) for strength athletes. Fortunately, this quantity of protein can be obtained in a mixed diet and inadequate protein intake should not be a serious problem for most athletes assuming their diet comes from a wide variety of foods and they are careful to consume adequate energy. Populations at greatest risk for getting insufficient protein include any physically active group that restricts energy intake (those on diets) or high quality protein sources (vegetarians, seniors, women) as well as any group that has a requirement higher than normal due to other existing conditions (growing individuals). Future studies should focus on these groups. Moreover, few exercise performance measures have been made so any negative effect of insufficient dietary protein on athletic success needs to be determined. Supplementation of several individual amino acids may be beneficial for athletes but considerable potential risk is also present. Intake of large quantities of individual amino acids is not recommended until much more information is available. Systematic study of other constituents of high quality protein sources relative to their potential to stimulate muscle growth and/or exercise performance is needed.

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