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A Critical Examination of Dietary Protein Requirements, Benefits, and Excesses in Athletes

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There is likely no other dietary component that inspires as much debate, insofar as athletes are concerned, as protein. How much dietary protein is required, optimal, or excessive? Dietary guidelines from a variety of sources have settled on an *adequate* dietary protein intake for those over the age of 19 of ~0.8–0.9 g protein·kg body weight^{-1}·d^{-1}. According to U.S. and Canadian dietary reference intakes (33), the recommended allowance for protein of 0.8 g protein·kg^{-1}·d^{-1} is "the average daily intake level that is sufficient to meet the nutrient requirement of nearly all [~98%] . . . healthy individuals" (p. 22). The panel also stated, "in view of the lack of compelling evidence to the contrary, no additional dietary protein is suggested for healthy adults undertaking resistance or endurance exercise" (33, p. 661). Currently, no group or groups of scientists involved in establishing dietary guidelines see a need for any statement that athletes or people engaging in regular physical activity *require* more protein than their sedentary counterparts. Popular magazines, numerous Web sites, trainers, and many athletes decry protein intakes even close to those recommended. Even joint position stands from policy-setting groups state that "protein recommendations for endurance athletes are 1.2 to 1.4 g/kg body weight per day, whereas those for resistance and strength-trained athletes may be as high as 1.6 to 1.7 g/kg body weight per day" (1, p. 1544). The divide between those setting dietary protein requirements and those who might be making practical recommendations for athletes appears substantial, but ultimately, most athletes indicate that they consume protein at levels beyond even the highest recommendations. Thus, one might conclude that any debate on protein "requirements" for athletes is inconsequential; however, a critical analysis of existing and new data reveals novel ideas and concepts that may represent some common ground between these apparently conflicted groups. The goal of this review was to provide a critical and thorough analysis of current data on protein requirements in an attempt to provide some guidance to athletes, trainers, coaches, and sport dietitians on athletes' protein intake. In addition, an effort was made to clearly distinguish between "required" dietary protein, "optimal" intakes, and intakes that are likely "excessive," perhaps not from the standpoint of health, but certainly from the standpoint of potentially compromised performance.

Key Words: amino acid, leucine, oxidation, carbohydrate, performance

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Any person with even a rudimentary familiarity with the area of nutrition and athletes knows that there is an apparent conflict between the scientific bodies that have established the dietary guidelines for protein (33) and numerous popular and even published positions on how much dietary protein athletes require (1). A number of recent and very informative reviews are available in which recommendations for dietary protein in athletes are assessed and scrutinized (62, 63, 71, 79). In light of these recent publications it seems that the reader would be best served to refer to those articles for all of the classic "arguments" in this area. Thus, instead of revisiting the same data and points of contention laid out in previous reviews (62, 63, 71, 79), this review has the goal of providing some kind of reconciliatory focus on the apparent "controversy" over whether or not athletes have elevated needs for dietary protein, whether the same athletes could derive some benefit from additional dietary protein over and above the recommended dietary allowances (RDA), and at what intakes protein might become excessive and a potential risk for compromising not necessarily health but performance.

Revision of the Canadian recommended nutrient intakes and U.S. RDAs to a model of nutrient adequacy and an upper limit was the basis for the development of the dietary reference intakes. The dietary-reference-intake estimations now include an estimated average (population) requirement, an RDA, and a tolerable upper limit, which is a threshold above which adverse effects of higher nutrient intakes appear to increase. Figure 1(A) on the next page shows this model in schematic form. In addition to the dietary-reference-intake recommendations for nutrient intake is a series of acceptable macronutrient distribution ranges (AMDRs). The AMDRs establish a large degree of latitude in what is an acceptable partitioning of macronutrients that would, with good likelihood, meet the nutritional needs of most people. These AMDRs are summarized in Table 1 below, which also contains our attempt to define an athlete-based AMDR derived from knowledge of carbohydrate "needs" in the case of competitive endurance athletes and retrospective estimates of protein "needs" for strength- and power-training athletes.

Table 1 Acceptable Macronutrient Distribution Ranges (AMDR) as Defined by the Institute of Medicine (IOM) (33) and as Viewed by Endurance and Strength Athletes as Sufficient

Macronutrient	Dietary energy (AMDR)[a]	Dietary energy (endurance athlete)[b]	Dietary energy (strength athlete)[c]
Carbohydrate	45–65%	55–80%	30–65%
Fat	20–35%	10–25%	15–30%
Protein	10–35%	10–20%	20–40%

[a]The AMDR as defined by the IOM is "a range of intakes for a particular energy source that is associated with reduced risk of chronic diseases while providing adequate intakes of essential nutrients" (33, p. 14). [b]Derived based on recommendations for carbohydrate intake for optimizing performance (12, 13) and working upward from those estimates, including a required amount of protein based on retrospective nitrogen-balance estimates (79), as well as allowances for the increased energy needs of these athletes. Fat percentages are derived by difference. [c]Derived based on recommendations of protein "requirements" from retrospective nitrogen-balance analysis (63) and working upward from those estimates to include sufficient nutrients for health, as well as the elevated energy requirements for these athletes to maintain and increase skeletal-muscle mass.

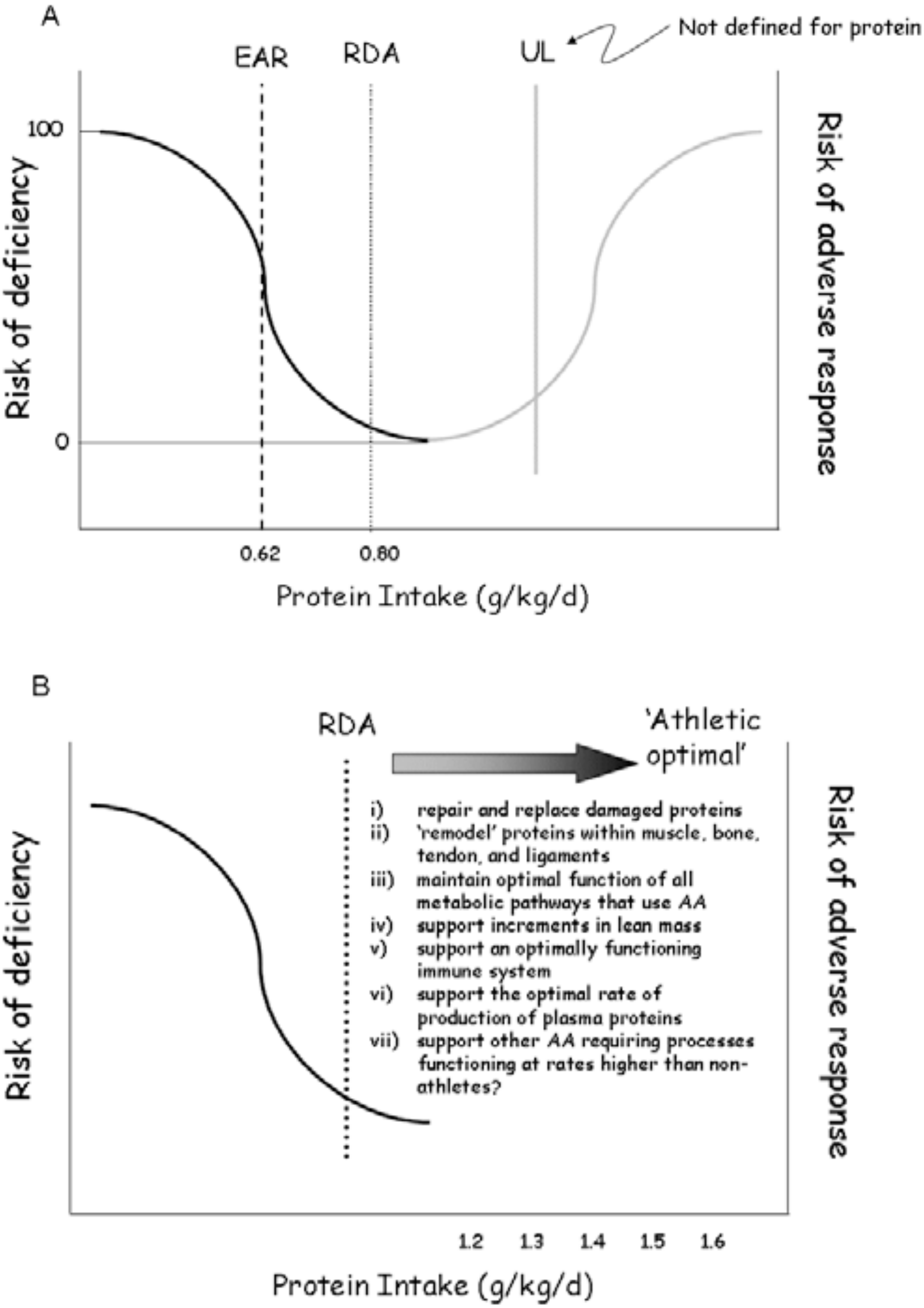

Figure 1 — Schematic representation of how increasing dietary intake protein requirements are met for (A) a sedentary population and (B) a group of athletes, with the "rationale" for why an athlete may have a higher than normal protein requirement. EAR indicates estimated average (population) requirement; RDA, recommended dietary allowance; and UL, upper limit.

Inherent Differences of Opinion

There are a number of interesting and important points about protein to address with respect to the recommendations made by the Institute of Medicine (IOM) (33):

- The RDA for protein for men and women age 19 years or older is 0.8 g of good-quality protein·kg^{-1}·d^{-1}. Using "athletic" reference body weights of 80 kg for men and 65 kg for women, the RDA equates to 64 g/d for men and 52 g/d for women.
- There is no tolerable upper limit for dietary protein or for any individual amino acid, although caution was advised if the intake of specific individual amino acids exceeded that normally present in the diet from foods (see [33] for details).
- The AMDR for total protein could not truly be established. Thus, the range of protein intake recommended in the diet was determined as the amount remaining after fat and carbohydrate needs are met. The IOM report states that "to complement the AMDRs for fat . . . and carbohydrate . . . for adults, protein intakes may range from 10 to 35% of energy intake to ensure a nutritionally adequate diet" (33, p. 844).
- What also needs to be highlighted is the fact that the protein RDA is *not* established as a guideline for how much protein people *should* be consuming but instead is a minimal estimate and one that is, even by the admission of those setting the protein RDA, based on a faulty method.

Part of the apparent disagreement between those deriving dietary guidelines and athletes and sports practitioners may well be the focus on the RDA, which establishes a level of protein that will replace losses and thus prevent deficiency. The methodology used by the IOM in establishing the protein RDA was nitrogen balance (33, 68). Use of nitrogen balance is likely a completely adequate and acceptable method for establishing nitrogen or amino acid requirements necessary to prevent deficiency. It is, however, possible or even likely that the same method is inadequate to establish intakes optimal for maximizing resistance-training-induced gains in muscle mass and strength and resistance- or endurance-training-induced adaptations in metabolic function. In fact, Millward has raised the possibility of such a concept, calling it the anabolic drive (56, 57). Defining requirements in terms of preventing deficiency would, from an athlete's perspective, hardly be considered a position from which to frame his or her "requirement" for dietary protein; hence, an inherent tension already exists between the 2 parties.

Nitrogen balance has long been recognized as an inherently flawed method for determining protein needs because of a number of methodological limitations such as implausibly high nitrogen balances typically observed with high protein intakes, increased economy of nitrogen use with low protein intakes, and often estimated rather than measured dermal and miscellaneous obligatory losses of nitrogen (33). From an athlete's perspective it is also important to realize that regardless of whether nitrogen balance is achieved at a particular protein intake, it is possible that the level of protein consumed is less than required to optimize all aspects of muscle mass, muscle function, and muscle metabolic processes. In addition, even at marginal intakes nitrogen equilibrium can be attained by adaptive and potentially accommodative down-regulation of protein-requiring processes (92). In addition, one needs to appreciate that as individuals adapt to less than adequate protein intakes they do so by lowering nitrogen excretion (68, 92, 93) such that there is no apparent relationship between nitrogen balance and muscle mass, let alone muscle function, which is a critical measure for athletes but one that has never been measured in the context of studies of protein adequacy. The last 2 points are difficult questions to assess, however, and would require long-term studies employing very intricate and revealing measures. More important from an athlete's perspective is the idea of whether protein intakes higher than the RDA translate into improved competition performance. This is an important consideration if we are to make arguments directed at optimizing physiological function based on protein intakes that would likely exceed the RDA; namely, is there benefit to consuming protein at levels higher than the RDA, and, if so, how much higher?

The choice of endpoints in studies of protein requirements also needs to be evaluated. Although attaining nitrogen balance per se is likely a healthful and adequate endpoint for sedentary individuals, it is questionable whether the same can be said for athletes. For those wishing to gain lean mass, for example, positive nitrogen balance is the desired goal. This is presumably because of the periodic stimulation of muscle protein synthesis, which, if it is to support the net gain of new proteins, would require net extra amino acids—for review see (62, 63, 71, 72). For an endurance athlete the goal would likely relate to balancing the loss of leucine, an amino acid that has been shown to be oxidized to an appreciable extent during endurance exercise (42–44, 50, 64), and also to support the increased protein synthesis that occurs after this form of exercise (15, 51, 76). Thus, whatever the end outcome of any study of dietary protein needs or optimal requirements for athletes, the model may be quite different than that used by the IOM to define the protein RDA. A scheme for understanding how an athletes, or their trainers and coaches, might view their need for dietary protein and what "athlete-specific" outcomes might be considered is presented in Figure 1(B). Regrettably, at this time it is not possible to ascertain what levels of protein would promote the necessary adaptations to support optimal function of all protein-requiring processes or optimal capacity for athletic performance.

Arguments for *Reductions* in Protein "Need"

Incongruent to the general belief of many athletes and their coaches, published position stands (1), and a number of viewpoints (62, 63, 79), there is another opinion that exercise per se actually *reduces* the overall requirement for dietary protein (14, 30, 58, 87). The elegantly controlled studies conducted by Butterfield et al. (14, 87) are often cited in support of this argument but are strongly criticized because the exercise intensities used in them do not begin to approach those in which most endurance athletes regularly engage. The implications of such criticisms are of course that more intense exercise will increase amino acid catabolism or reduce protein synthesis (i.e., the ability to retain amino acids); however, neither of these suppositions has ever been investigated.

Two recent longitudinal studies, in which an accrual of lean mass was observed with resistance training, showed greater economy of nitrogen retention when the subjects consumed what was determined, through nitrogen balance, to be sufficient protein (1.2–1.4 g protein·kg^{-1}·d^{-1}) and energy to cover needs after a strenuous resistance-training program lasting 12 wk (30, 58). It may be that the anabolic stimulus of weightlifting is enough to stimulate muscle protein synthesis such that this tissue becomes a greater site of disposal of amino acids in both fed and fasted states, possibly at the "expense" of other amino acid–requiring processes. As such, these data (30, 58) may not necessarily be indicative that resistance training reduces protein requirements per se, but instead may be evidence of a shift in the hierarchy of amino acid–requiring processes toward muscle protein synthesis getting a "greater share" of circulating amino acids in both fasted and fed states. The results obtained with resistance exercise (30, 58) may be markedly different from those seen with endurance exercise because resistance exercise is fundamentally anabolic and stimulates protein synthesis, such that loss of amino acids in the fasted state is reduced for up to 48 h (65). In contrast, the anabolic nature of endurance exercise is far weaker than that of resistance exercise, and the improved net retention of amino acids in muscle appears to be much more transient (76).

There is a large body of evidence showing that provision of protein/amino acids supports increased rates of protein synthesis and positive protein balance after both endurance exercise (37, 48) and resistance exercise (52, 69, 82, 83, 85). These data, in and of themselves, provide some credence to an argument for increased protein for athletes above a requirement level. What is not clear, however, in any of these studies is exactly how much of the supplemental protein is directed toward muscle protein synthesis, which goes directly to the question of how much extra protein is needed to support gains in muscle protein mass. Using urea tracers, a number of investigations on postexercise amino acid provision have shown no increase in urea production (52, 69, 82, 83, 85), arguing that the ingested supplement is effectively and efficiently used by muscle protein synthesis and other amino acid–requiring processes. On the other hand, the situation of endurance exercise is difficult to assess because in this case the stimulus is not anabolic and does not ultimately result in a net accumulation of muscle contractile protein mass (as is the case with resistance exercise). The argument often given is that extra protein for endurance athletes is required because endurance exercise increases amino acid oxidation (25, 42–44, 50, 79, 86, 90); however, it has never been shown, at least to our knowledge, that any amino acid other than leucine is oxidized to a substantial degree during exercise. Based on an average human body-tissue leucine content of 590 µmol/g protein (70), if x amount of leucine is oxidized during an exercise bout then $x/590$ is equivalent to the number of grams of tissue protein broken down. Such a calculation relies, however, on a number of very tenuous assumptions that are not tested in most experimental paradigms, so increased leucine oxidation during endurance exercise may mean an increased need for dietary leucine and not necessarily an increased need for dietary protein. In a practical sense, however, unless leucine supplements are ingested, an increased dietary leucine requirement would represent an increased need to ingest proteins (especially those containing leucine, such as lean meats and the dairy proteins whey and casein).

Beyond "Requirements" to "Optimal" Intakes

In the most recent reviews of protein "requirements" for strength-training athletes it was estimated, based on a meta-analytic regression, that a daily intake of ~1.33

g protein·kg^{-1}·d^{-1} is required to remain in nitrogen balance (66% greater than the Canadian/U.S. RDA) (63). Protein requirements for endurance athletes were estimated to be ~1.11 g protein·kg^{-1}·d^{-1} but could be as high as 1.6 g protein·kg^{-1}·d^{-1} in individuals exercising very intensely (79). Accepting all of the shortcomings of nitrogen balance, the method used to derive the previous estimates (63, 79) is identical to the approach that was used to derive the current protein RDA (i.e., an analysis of pooled nitrogen-balance data from human studies) (33, 68). If these estimates are reasonable, do these protein intakes represent an optimal level? If we define an optimal level as being a protein intake that would 1.) support an athlete's ability to repair and replace any damaged proteins (resulting potentially from oxidative stress or mechanical disruption); 2.) adaptively "remodel" proteins in structures such as muscle, bone, tendon, and ligaments to better withstand the stress and strain imposed by training and competition; 3.) maintain optimal function of all metabolic pathways in which amino acids are participatory intermediates (which includes being oxidative fuels); 4.) support increments in lean mass, if desired; 5.) support an optimally functioning immune system; and 6.) support the optimal rate of production of all plasma proteins required for optimally physiological function, would the previous estimates of protein intake represent an optimal level?

If athletes' protein requirements were sufficient to support all of the aforementioned processes, the intake would not be a requirement to prevent deficiency but rather an intake that is optimal for the athletes' overall metabolism. In light of this, such an intake would obviously be greater than that of a sedentary individual because the nature of exercise is such that there is an up-regulation of protein-utilizing processes. At the same time, one could argue that optimal levels of dietary protein should not reach levels that promote excessive production of urea and higher than necessary oxidative losses of amino acids than those needed for optimal functioning, as just defined. Why is this? Why not simply consume lots of protein "just to make sure you're getting enough"? The simple argument is that ultimately nitrogen is still toxic to mammalian metabolic systems and cannot be stored or amino acid pool sizes expanded ad infinitum to accommodate "extra" amino acids. Consequently, nitrogen consumed in excess of what is *immediately* required to support the optimal rates of amino acid–utilizing functions outlined here will ultimately result in urea production. It is important to recognize that protein ingestion when considered in this context needs to be evaluated from meal to meal because it is the immediate handling of ingested nitrogen that will influence the rate of urea production and amino acid oxidation. It is worthwhile noting that Cuthbertson et al. (18) showed that an oral dose of 10 g of essential amino acids maximally stimulates muscle protein synthesis in both the young and the elderly. Because it appears that only essential amino acids are required to maximally stimulate muscle protein synthesis (84, 88), these data (18) warrant serious consideration.

If we examine the essential amino acid composition of milk proteins, meat, and eggs, 10 g of essential amino acids translates to ~25 g of each of these protein sources (most high-quality proteins are 40% essential amino acids by content), which represents ~750 mL of skim (nonfat) milk, 4 or 5 eggs, or ~100 g of cooked lean beef. If we were to use these data and assume that a similar anabolic response occurs after each meal when consumed, say, 4 times per day, then a daily protein intake would be, at a minimum, 100 g to achieve the "maximal" anabolic response in a nonexercising individual. Furthermore, we have data that suggest that the dose of protein required to maximally stimulate muscle protein synthesis after an isolated bout of resistance exercise is similar (or possibly lower at ~8.5 g essential amino acids or ~20 g protein) to that seen at rest (D.R. Moore and S.M. Phillips, unpublished observations). Thus, from the standpoint of maximally stimulating muscle protein synthesis, a dose of ~20–25 g of high-quality intact protein (such as dairy, eggs, or lean meat) appears sufficient. What is missing from these data, however, is knowledge of how the other amino acid–requiring processes highlighted as being part of optimal protein intake are stimulated by this dose of protein.

Ultimately, the answer to the question of how much protein is required to, for example, support optimal immune-system function or to allow optimal flux through intermediary amino acid–requiring metabolic pathways is relatively difficult to answer directly. Thus, a default position of many athletes is to consume very large amounts of protein in the hope that this will be more than enough to satisfy the myriad of physiological processes that require dietary protein but in effect will do them little harm from an overall health perspective. However, the potential for a chronically high-protein diet to influence the metabolic fate of dietary amino acids requires consideration. For example, habitual consumption of a high-protein (1.8 $g \cdot kg^{-1} \cdot d^{-1}$) diet increases leucine oxidation at rest and during moderate exercise (10), demonstrating that the body adapts to relatively high protein loads by increasing the capacity for amino acid catabolism. Because the pathways for oxidative amino acid catabolism adapt to the diet and may act as the main regulator of protein stores (53, 54, 67), it is likely that habitual consumption of a high-protein diet begets the requirement for greater protein intakes. Therefore, from the standpoint of dietary sources of protein, consuming large amounts is likely to have little impact on an athlete's long-term health (see below); whether it affects performance, however, is debatable. In the absence of an upper limit for protein (33), should athletes, dietitians, coaches, or health care providers be concerned about protein intakes in excess of 2–4 times the RDA? The operative question is really, when do high protein intakes become "excessive"? What defines excess and what impact could this have on athletes' ability to perform or on their long-term health?

From "Optimal" to "Excessive"

Dietary surveys of athletes, particularly strength- and power-training athletes and bodybuilders, indicate that dietary protein intakes in the range of 2–2.5 g $protein \cdot kg^{-1} \cdot d^{-1}$ and up to as high as 3 g $protein \cdot kg^{-1} \cdot d^{-1}$ (22, 23, 26, 34–36, 80) are not unusual. Protein intakes are not normally as high in endurance-trained athletes, usually falling in the range of 1.2–1.6 g $protein \cdot kg^{-1} \cdot d^{-1}$ (reviewed in [79]) and tending to be lower in endurance-trained women (4, 19, 77, 78). Hence, as a general rule it appears that the strength or power athlete and bodybuilders would be more at risk for excessive protein intakes. A pragmatic question is what are the true downsides of such high protein intake?

From a health standpoint the response often given is the potential for high protein intakes to result in reduced peak bone mass and impaired renal function. Contradicting those arguments is the knowledge that certain populations consume more protein than the RDA, up to 3.0 g $protein \cdot kg^{-1} \cdot d^{-1}$, without apparent negative health effects, at least not those related to dietary protein. For example, the Northern Canadian and Alaskan Inuit have extraordinarily high protein intakes throughout their lives (39, 40, 61, 74). Based on estimated energy intakes that match an expenditure of twice the basal metabolic rate, an intake of 3.0 g protein/kg translates into an overall protein:energy ratio in the diet of 34%, or very close to the highest end of the AMDR in terms of protein (10–35%) (55).

Insofar as protein intake and bone are concerned, there are some studies that have shown increased calciuria with higher protein intakes and a subsequent increased risk for bone fracture or osteoporosis (24); however, several studies have supported a contrary position (59, 89). In fact, the relationship between protein and bone health has recently been highlighted to be a positive one; that is, the more dietary protein consumed the greater the peak bone mass achieved (reviewed in [7]). The mechanism underpinning the greater bone mass with higher intakes of dietary protein appears to be mediated through levels of IGF-1 (7). Increased protein intake may also interact with the high forces generated during resistive-type activities, which are potent stimuli for increasing IGF-I (both systemically and locally) (3, 29, 60), to further increase peak bone mass. Thus, as a health-related reason for why high dietary protein levels might be deleterious for athletes or for the population in general, reduced peak bone mass appears to be a dubious argument at best.

Increased risk of developing renal disease is also an often-stated consequence of persistently high dietary protein intakes. Protein can form up to 35% of dietary energy (as reflected in the AMDR), which would almost certainly provide the RDA and likely much more, unless very low energy was being consumed. In establishing the RDA, the IOM report reviewed the impact of high protein intake on renal disease and concluded that levels of dietary protein are not related to progressive decline in kidney function with age (33). Other studies examining protein intake and renal function support this conclusion (49–51). Martin et al. (49) showed that protein restriction may be appropriate for the treatment of existing kidney disease but that evidence for a detrimental effect of high protein intakes on kidney function was marginal in healthy individuals consuming a high-protein Western diet. The notion that protein-restricted diets decrease the risk of developing kidney disease in the general population is not supported by the scientific literature—in fact, preliminary studies show a positive effect of higher protein diets on risk factors for kidney disease, including obesity, hypertension, and diabetes (45–47, 66, 94, 95). A review by Bernstein et al. (5) compared the effects of animal and vegetable protein on kidney function. In short-term clinical trials, egg white, dairy, and soy consumption did not affect renal function, whereas other animal-protein intake elicited some response. The researchers noted that "from these studies, it is difficult to conclude whether or not there is a long-term association between amount of animal or vegetable protein intake and change in normal renal function" (5, p. 647). Hence, it is difficult to make a convincing argument against a higher than normal protein intake for those with normal renal function, at least in terms of adverse health consequences.

The Impact of Energy Intake

A discussion of protein "requirements" and "optimal" protein intakes for athletes would be incomplete without a discussion of the impact of dietary energy intake. Assuming that energy balance is a desired goal, increased energy intake is needed to balance exercising energy expenditure; nevertheless, additional protein intake need not be overly high to achieve nitrogen balance. This is particularly true if the increased energy comes from carbohydrate (73), which, owing to its ability to stimulate insulin release, can markedly suppress proteolysis, consequently improving nitrogen balance (9, 16). However, as previously stated, most athletes are not seeking nitrogen balance (i.e., simply getting enough protein to offset nitrogen loss) but instead are looking for an optimal protein intake. It is worth noting that, even in the complete absence of protein intake, after exercise leg-muscle protein balance can be brought to levels not different from zero (i.e., no net loss or gain of proteins) simply by ingesting carbohydrates alone (9, 16).

In a previous review (62), we examined studies that had shown a marked fat loss and a simultaneous "sparing" of muscle mass by inducing an energy deficit with varying macronutrient ratios. Without going into the same degree of detailed review here we direct the reader to a recent meta-analysis showing that during hypoenergetic periods it appears that lower carbohydrate (less than 40% of total energy) and higher protein (> 1.05 $g \cdot kg^{-1} \cdot d^{-1}$) intake result in increased fat-mass loss and lean-mass preservation than diets higher in carbohydrate and lower in protein (38). In addition, Layman et al. (46) showed that a hypoenergetic diet containing lower carbohydrate and higher protein (carbohydrate-to-protein ratio of 1.6) combined with the addition of primarily endurance but also some resistive exercise appeared to be the most effective strategy for promoting fat loss and preserving lean mass. This finding may not be surprising when one considers that endurance exercise (to a small degree) (51, 76) and resistance exercise (to a very large degree) (6, 65) are anabolic in that they stimulate muscle protein synthesis even in the fasted state, forcing an increased net "conservation" of amino acids arising from proteolysis. From an athlete's perspective, however, the important point here is that for most sports it is recognized that a higher lean-to-fat-mass body-composition ratio typically translates into a competitive advantage. Thus, we concluded previously (62) that a lower carbohydrate, higher protein hypoenergetic diet, particularly when combined with exercise, is likely of substantial benefit for athletes if they wish to attain the associated performance advantage of modifying their body composition by losing stored body fat. Of course, such a strategy is not without the obvious limitation that lower carbohydrate intake for athletes will likely lead to lower muscle glycogen stores (11–13). In this sense, athletes who adhere to this dietary practice are depriving themselves of the very fuel that is by far the preferred substrate to power muscular contraction—reviewed in (11–13).

Timing Is Important

When it comes to stimulating new muscle protein accretion via resistance exercise it appears that immediate postexercise protein supplementation is beneficial. Results of a number of studies in which protein was given to subjects postexercise, as a supplement, appear to agree with a general statement that the timing of protein consumption postexercise may be a determinant of muscle mass and strength gains. Although acute studies suggest that muscle is sensitive to the provision of nutrients (especially amino acids) for up to 3 h after resistance exercise (69), longitudinal training studies suggest that increases in strength and muscle mass are greatest when protein is consumed immediately after exercise (2, 20, 31, 32). For example, Esmarck et al. (20) reported that delaying the postexercise delivery of a protein-containing supplement to elderly men by a mere 2 h completely prevented exercise-induced hypertrophy and slowed strength gains. In addition, strength and muscle-mass gains in patients who had just undergone knee surgery were promoted to a greater degree by protein and carbohydrate consumption than carbohydrate alone or a placebo (32). Gains in muscle-fiber size were seen with young men training for 14 wk only if they consumed protein versus isoenergetic carbohydrate postexercise (2). Cribb and Hayes (17) recently reported that a creatine- and protein-containing supplement consumed immediately before and after exercise resulted in more gains in lean mass, strength, and Type II muscle-fiber area than seen in a group who got the same supplement but at different times of day. We recently reported that in groups of young men immediately consuming either skim milk, the equivalent amount of protein as soy, or isoenergetic carbohydrate after resistance exercise, the greatest lean-mass gains were seen in the milk-supplemented group (31). Hence, we would propose that our data (31), taken together with previous data from chronic studies manipulating postexercise protein consumption (2, 17, 20, 32), support the general thesis that immediate consumption of protein, particularly high-quality milk protein (31), after resistance exercise serves to maximize exercise-induced increases in muscle mass. Furthermore, consumption of energy in the form of carbohydrate after a resistance-exercise workout, when ingested alone (i.e., without protein), limits resistance-exercise-induced gains in muscle mass.

Higher Protein and Performance: A Potential Adverse Effect

Is it possible that there actually is an upper limit for protein intake? The short answer is yes, and it is 35% of a one's energy intake, particularly if one is in energy balance. If taken to extremes higher dietary protein intakes would, unless weight gain were a desired goal, have to displace another dietary macronutrient. If it is dietary lipid that is displaced, the outcomes are not likely to be of great concern. If, however, the increased consumption of dietary protein results in a lower dietary carbohydrate intake, performance could be compromised. This may be a situation of greater concern if the athlete has voluntarily assumed an energy deficit to change his or her body weight and composition. Figure 2 shows how increasingly higher protein intake, assuming that fat is held constant, will come at the expense of dietary carbohydrate to the point that carbohydrate could become limiting, according to the necessary dietary intake levels required to maintain adequate muscle glycogen, for training and performance (12, 13). This situation would, of course, be exacerbated by dietary energy restriction.

To restore glycogen during high-intensity and -volume training (i.e., 2 or 3 training sessions per day), estimated carbohydrate requirements for athletes have ranged from as little as 5 g up to as high as 8–10 g carbohydrate·$kg^{-1}·d^{-1}$. It is unlikely, at least at the very high end of the suggested carbohydrate intakes, that any athletes other than highly competitive triathletes, runners, or cyclists would require such intakes to sufficiently maintain the ability to train and perform. Thus, when would lower carbohydrate intakes begin to compromise performance, and at what specific level? The answer is likely to be sport and training specific; however, we must stress that even high-intensity, short-duration muscular efforts (i.e., sprinting and lifting)

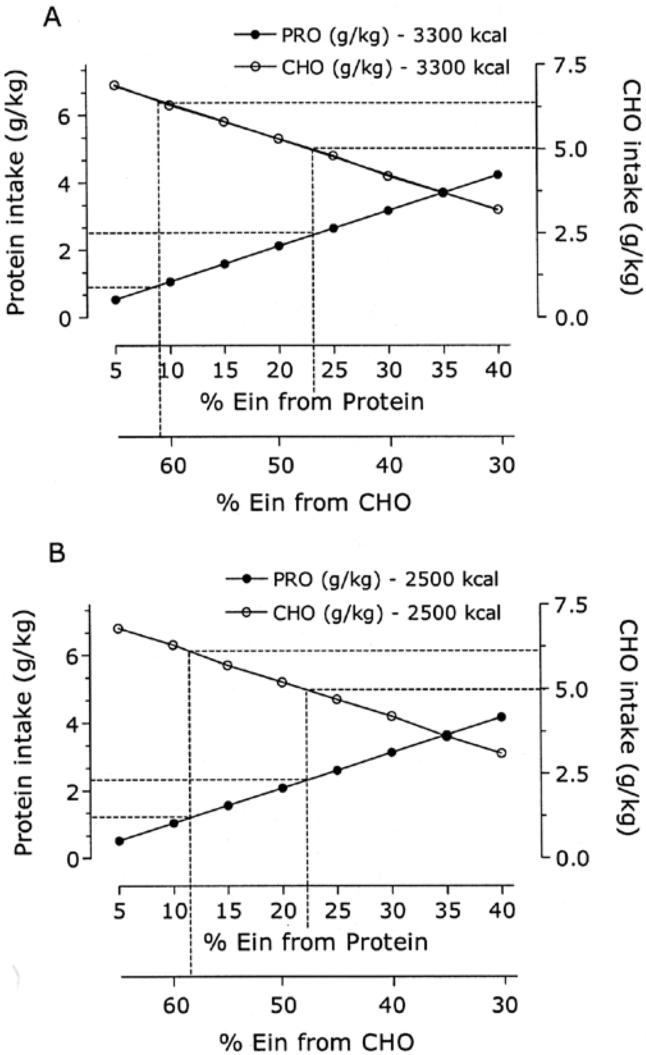

Figure 2 — Relationship between dietary energy as a percentage of carbohydrate (energy in [Ein] from CHO) and protein intake (Ein from protein) plotted against both protein and carbohydrate intake in g/kg body weight. (A) A 70-kg male athlete consuming 3300 kcal (13.8 MJ)/d. The dashed lines indicate that consumption at the recommended daily allowance for protein (0.8 g protein·kg^{-1}·d^{-1}—8% of dietary energy as protein) would result in a carbohydrate intake of 6.3 g·kg^{-1}·d^{-1}. This intake is considered high enough to support carbohydrate needs for an athlete training at moderate duration and low intensity (13). When the same athlete holds fat intake constant at ~20% of energy intake but consumes protein at ~23% of total energy (2.5 g protein·kg^{-1}·d^{-1}), carbohydrate intake at the same energy intake is 5 g·kg^{-1}·d^{-1}. This intake is considered marginal in terms of what is required for replenishment of glycogen and performance (13). (B) The same relationships for a 56-kg female athlete consuming 2500 kcal (10.4 MJ)/d.

rely heavily on carbohydrate (21, 41, 49, 75, 81). Given that it is resistance-training and power-lifting athletes who tend to consume more protein, such individuals may be at greater risk for lower than optimal carbohydrate intakes to support the most intense training effort possible. Data from Martin et al. (49) showed that with 3 sets of biceps curls (8–10 reps/set) performed at a weight providing 80% of the subjects' single-repetition maximum load (1-RM), muscle glycogen concentration was reduced by almost 35% from starting levels. Similar results have been obtained by others (21, 75, 81). In addition, carbohydrate provision improves weightlifting performance during a bout of resistance exercise lasting 60 min or more, which is a duration that is similar to traditional training bouts performed by many athletes (27, 28). These results provide strong support for the idea that carbohydrate is an important and potentially limiting substrate even during resistance-exercise workouts (27, 41, 81). Another line of evidence to support the concept that dietary carbohydrate would be important for strength-training athletes is that postexercise ingestion of carbohydrate appears to augment the rise in muscle protein synthesis brought about by protein/amino acids (8, 52, 69, 83, 84, 91). The quantity of carbohydrate necessary to achieve this effect (35 g) is minimal in comparison with the carbohydrate intakes suggested to completely replenish muscle glycogen, which are in the range of 1–1.2 g carbohydrate$\cdot$kg$^{-1}\cdot$h^{-1} (11–13). Nevertheless, from a practical standpoint athletes need to consider their postexercise carbohydrate intake, in addition to their protein intake, in order to optimize performance.

Conclusions and Practical Recommendations

To attain peak levels of performance athletes clearly need to be aware of their dietary intake of protein, as well as carbohydrate and a number of other micronutrients and minerals. Highly detailed and refined guidelines for intakes, however, are likely to be confusing for most athletes. Notwithstanding, it appears that emerging dietary guidelines for protein are in the range of 1.2–1.6 g protein$\cdot$kg$^{-1}\cdot$d^{-1}. This level is greater than the RDA, with the general recommendation that the RDA is a protein intake designed simply to alleviate deficiency. More important, it is an intake that appears, based on experimental evidence (mostly nitrogen balance), to be adequate and more than sufficient. Should athletes aim to meet or exceed this intake? Quite simply, in the absence of evidence suggesting that higher intakes are beneficial, it is not yet possible to say that they will be beneficial. What appears to be critical, as with the recommendations for carbohydrate, is that timing of ingestion is very important. Put simply, protein should be consumed early during the postexercise recovery phase (i.e., immediately to 1 h after exercise). Protein quality also appears to be important in maximizing the accretion of muscle proteins, so athletes would do well to focus on high-quality protein sources such as dairy protein, eggs, and lean meat. When athletes find it inconvenient to consume such protein sources, more portable protein sources, particularly protein supplements, offer a practical alternative. The content of these protein supplements should be closely scrutinized by athletes for quality, however, because protein bars and drinks are highly heterogeneous in terms of their composition. The high-quality protein dose that appears to maximally stimulate muscle protein synthesis is close to 20–25 g; above this point protein synthesis is not additionally stimulated, but increases in amino acid oxidation and urea synthesis may result.

As a closing remark, it is tempting to dismiss the notion of protein intake for athletes as relatively unimportant in the grand scheme because all athletes appear to consume enough. Adequate protein consumption is not always the case, however, particularly when female athletes are concerned. More important, athletes, dieticians, and coaches alike would be remiss in their attention to details and advice to simply assume that the athletes get enough protein and that there is nothing more that they have to be concerned about. As noted by Burke et al. (12), dietary guidelines for athletes are almost unanimous in their recommendation of high carbohydrate intakes for enhancing performance, and yet many top athletes do not appear to achieve the levels recommended. Quoting Burke et al., "The real or apparent failure of these athletes to achieve [exceed] the daily CHO [protein] intakes recommended by sports nutritionists does not necessarily invalidate the benefits of meeting [following] such guidelines" (12, p. 267). Thus, hidden in the details of the recommended guidelines for protein intake for athletes are a number of points regarding timing and composition (quality), as well as consumption in combination with macronutrients such as carbohydrate; attention to these details, we contend, will enable athletes to perform to the best of their potential.

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