

Dietary protein for athletes: from requirements to metabolic advantage

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Abstract: The Dietary Reference Intakes (DRI) specify that the requirement for dietary protein for all individuals aged 19 y and older is 0.8 g protein·kg⁻¹·d⁻¹. This Recommended Dietary Allowance (RDA) is cited as adequate for all persons. This amount of protein would be considered by many athletes as the amount to be consumed in a single meal, particularly for strength-training athletes. There does exist, however, published data to suggest that individuals habitually performing resistance and (or) endurance exercise require more protein than their sedentary counterparts. The RDA values for protein are clearly set at "...the level of protein judged to be adequate... to meet the known nutrient needs for practically all healthy people...". The RDA covers protein losses with margins for inter-individual variability and protein quality; the notion of consumption of excess protein above these levels to cover increased needs owing to physical activity is not, however, given any credence. Notwithstanding, diet programs (i.e., energy restriction) espousing the virtue of high protein enjoy continued popularity. A number of well-controlled studies are now published in which "higher" protein diets have been shown to be effective in promoting weight reduction, particularly fat loss. The term "higher" refers to a diet that has people consuming more than the general populations' average intake of ~15% of energy from protein, e.g., as much as 30%–35%, which is within an Acceptable Macronutrient Distribution Range (AMDR) as laid out in the DRIs. Of relevance to athletes and those in clinical practice is the fact that higher protein diets have quite consistently been shown to result in greater weight loss, greater fat loss, and preservation of lean mass as compared with "lower" protein diets. A framework for understanding dietary protein intake within the context of weight loss and athletic performance is laid out.

Key words: lean mass, protein turnover, leucine.

Résumé : D'après les apports nutritionnels de référence (DRI), les besoins quotidiens de protéines chez les individus de 19 ans et plus sont de 0,8 g protéine·kg⁻¹·d⁻¹. Cette ration alimentaire recommandée (RDA) est dite convenable pour tous. Plusieurs athlètes, notamment ceux s'entraînant à la force, trouveraient cette quantité suffisante pour un seul repas. Selon quelques études, les individus s'adonnant régulièrement à des exercices de force et d'endurance auraient besoin de plus de protéines que leurs congénères inactifs. La ration protéique recommandée est bien établie comme étant « la quantité de protéines suffisante pour combler les besoins de nutriments d'à peu près toutes les personnes en bonne santé ». Cette ration tient compte de pertes de protéines, de la variation interindividuelle et de la nature des protéines; consommer un surplus de protéines pour combler les besoins accrus par l'activité physique ne semble pas crédible. Malgré cela, les régimes amaigrissants à forte teneur en protéines ont encore la cote. De nombreuses études bien structurées indiquent l'efficacité des régimes hyperprotéiques dans la perte de poids, notamment la perte de gras. Par forte teneur en protéines, on entend plus de protéines que n'en consomme la moyenne, soit 30%–35 % comparativement à ~15 %, ce qui est compris dans la fourchette de distribution acceptable des macronutriments (AMDR) selon les DRI. L'observation suivante est pertinente pour les athlètes et les cliniciens : comparativement aux régimes hypoprotéiques, les régimes hyperprotéiques causent systématiquement plus de perte de poids, plus de perte de gras et protègent davantage la masse maigre. Nous présentons un cadre de référence pour bien établir les besoins protéiques dans un contexte d'amaigrissement et de performance physique.

Mots clés : masse maigre, renouvellement des protéines, leucine.

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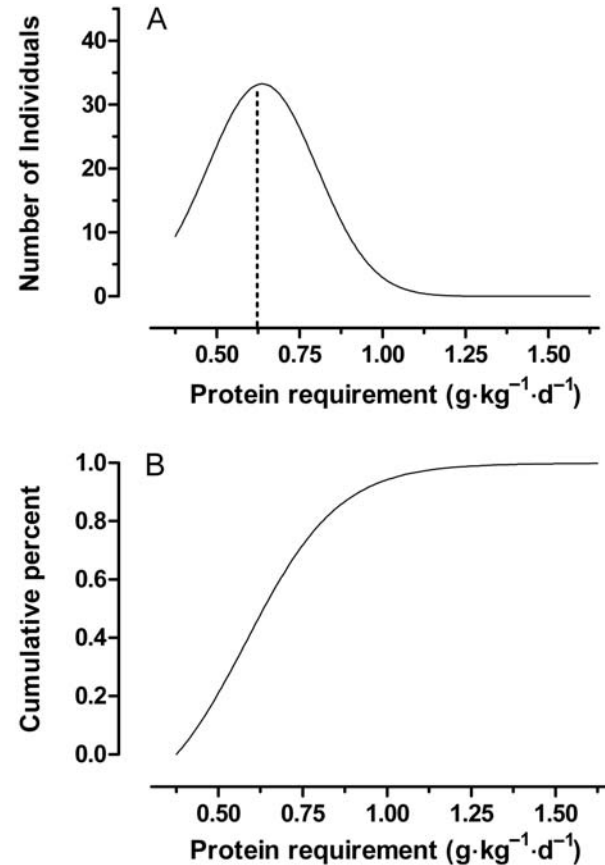
Introduction

It is likely fair to say that where an optimal dietary protein intake for athletes is concerned no greater dichotomy of opinion exists than between those who establish recommendations and the athletes themselves, particularly strength- and (or) power-training athletes. The published standards for dietary guidelines — the Dietary Reference Intakes (DRIs), assert that although protein is an essential nutrient, it is not required above a basal level not much more than that needed to cover daily body protein losses (Institute of Medicine 2005). At the same time, a large group of athletes and an industry devoted to supplemental protein sources argue that their experience tells them higher protein diets are beneficial and perhaps even necessary. As with most arguments of this type the truth may lie somewhere in between; however, it is prudent to review evidence that forms the basis of the arguments on both sides in an effort to come to an evidence-based conclusion on what dietary protein intake is appropriate. In this review, an appropriate intake of protein is defined as one that (i) allows maximal functioning of all protein-requiring processes in the body, particularly protein synthesis; (ii) does not promote significant elevations in urea synthesis and amino acid oxidation, which would create a situation of excessive amino acid oxidation and nitrogen loss, or excessive reliance on protein oxidation during prolonged exercise; and (iii) might allow beneficial physical adaptation to occur under certain conditions such as caloric deprivation. A brief review of how the Recommended Dietary Allowance (RDA) for protein is set and also what evidence exists to support the contention that dietary protein is required at greater than RDA levels for athletes is presented.

Establishing the RDA

This section will be relatively brief, since excellent recent reviews on this topic have appeared previously in this journal (Barr 2006; Zello 2006). The RDA for protein for persons 19 y and older is set at $0.8 \text{ g protein}\cdot\text{kg body mass}^{-1}\cdot\text{d}^{-1}$ (Institute of Medicine 2005). This intake is essentially set to cover basal losses of nitrogen and also has a margin for error of the general population's Estimated Average Requirement (EAR), plus two standard deviations. As a result, the RDA is said to cover the requirements of 97.5% of the population. The DRI data forming much of the basis of the RDA are from Rand et al. (2003) and encompasses 225 individuals and their protein requirement (Fig. 1). Suffice to say that most athletes, particularly those engaged in strength training and those concerned with gaining lean body mass, would believe that they are most assuredly in the 2.5% of the population not covered by the RDA. Of note to such athletes, however, is the fact that the DRI does not set a Tolerable Upper Limit (TUL) for protein; hence, there appears to be no cap on protein intake from an adverse health standpoint so far as the committee establishing the RDA for protein is concerned. As Zello (2006) points out, however, high protein intakes for those with pre-existing disorders, such as renal disease, are not recommended.

Fig. 1. Data adapted from Rand et al. (2003). (A) Data from 225 individuals showing their protein requirements, based on nitrogen balance data. Dotted line indicates the 50th percentile for individual's requirement for dietary protein. Note the skewed nature of the distribution toward protein requirements greater than the RDA. (B) Data from A shown as a cumulative percentage of individuals (total of 225) as a function of their protein requirements.



Protein requirements for athletes

Studies in which protein requirements have been examined in athletes have shown an increased requirement for protein in strength-trained (Lemon et al. 1992; Tarnopolsky et al. 1988, 1992) and endurance-trained athletes (Friedman and Lemon 1989; Meredith et al. 1989; Tarnopolsky et al. 1988). Quite simply, increased protein requirements for individuals engaging in resistive activities might be expected to come about owing to the need for "extra" dietary protein required to synthesize new muscle or repair muscle damage. On the other hand, endurance exercise is associated with marked increases in leucine oxidation (Lamont et al. 1999, 2001; McKenzie et al. 2000; Phillips et al. 1993), which would elevate overall requirements for protein (if other amino acids are oxidized to an appreciable extent), or at least for leucine. Conversely, other investigations have shown that increasing physical activity reduces requirement for protein (Butterfield and Calloway 1984; Todd et al. 1984). So, why is there a discrepancy? The protein used in those studies in which protein requirements were reduced was high-quality egg and milk protein (Butterfield and Calloway 1984; Todd et al. 1984), which may have allowed subjects to achieve a nitrogen balance at a protein intake

lower than that seen with lower-quality proteins. In addition, the intensity of the exercise performed by the subjects in studies in which protein requirements were elevated (Friedman and Lemon 1989; Lemon et al. 1992; Meredith et al. 1989; Tarnopolsky et al. 1988, 1992) was greater than that in studies in which requirements were reduced (Butterfield and Calloway 1984; Todd et al. 1984). Thus, the combination of higher-intensity exercise and the fact that leucine oxidation is proportional to exercise intensity (Lemon et al. 1982) means that a higher exercise intensity may have resulted in a higher requirement for protein.

Although there exist data to support the idea that protein requirements are higher in persons who are habitually exercising (Friedman and Lemon 1989; Lemon et al. 1992; Meredith et al. 1989; Tarnopolsky et al. 1988, 1992), all of the aforementioned studies have relied on the nitrogen balance methodology to establish protein requirements. This methodology is still used, in part, to establish the RDA intake for protein, which gives it some credence. However, there is a consistent and physiologically non-plausible result with nitrogen balance data at high protein intakes, which is an impossibly high retention of nitrogen. For example, at a protein intake of around 2.5–2.8 g protein·kg⁻¹·d⁻¹ body builders have been shown to be in positive nitrogen balance on the order of 8–20 g N·d⁻¹ (Lemon et al. 1992; Tarnopolsky et al. 1988, 1992). Since protein is, on average, 16% nitrogen by mass, this would mean these athletes would be retaining 50–125 g protein·d⁻¹, or 200–500 g·d⁻¹ when hydrated, as it exists in the body; obviously, such a result is physiologically impossible. This finding is more than likely the result of an expansion of the circulating urea pool and reflects a physiological limit on the rate at which urea can be excreted. It may also be that at high protein intakes there is a consistent overestimation of protein intake and underestimation of nitrogen excretion (Hegsted 1976; Young 1986; Young et al. 1987). Many of these shortcomings of nitrogen balance have long been recognized (Hegsted 1976; Young 1986; Young et al. 1987). The fact that a non-physiologically reasonable condition forms part of the basis on which conclusions regarding an adequate protein intake are based highlights the need for another approach to examining protein requirements; tracer-derived estimations of protein requirements are one alternative method. Using such an approach it was reported that consumption of a low-protein diet (0.86 g protein·kg⁻¹·d⁻¹) by a group of strength-training athletes resulted in an accommodated state in which whole-body protein synthesis was reduced as compared with medium- (1.4 g protein·kg⁻¹·d⁻¹) and high- (2.4 g protein·kg⁻¹·d⁻¹) protein diets (Tarnopolsky et al. 1992). No difference was seen in whole-body protein synthesis between the medium- and high-protein diets. On the high-protein diet, amino acid oxidation was elevated; however, indicating that this protein intake was excessive compared with requirements. It should be emphasized that these results do not mean that 1.4 g protein·kg⁻¹·d⁻¹ was required to cover dietary protein needs, but simply that 0.86 g protein·kg⁻¹·d⁻¹ was not sufficient to allow maximal rates of protein synthesis. It is not known what body proteins were being made at a submaximal rate, but if muscle protein synthesis were adversely affected, then clearly these data would be of relevance to athletes.

Recent work from our laboratory has shown that novices undergoing a strength-training program, during which they gained a significant amount of lean mass (2.5 kg), had a more positive whole-body nitrogen balance when consuming 1.2 g protein·kg⁻¹·d⁻¹ after as opposed to before training (Hartman et al. 2006). We also observed that tracer-estimated (oral [¹⁵N]glycine) protein turnover was reduced as a result of training, consistent with our nitrogen balance data. Together, these data support the concept that resistance training in novices, a group in whom one would expect to see a much greater need for dietary protein (vs experienced weightlifters who have reduced muscle protein turnover (Phillips et al. 1999), is actually a protein-conserving stimulus rather than one that results in increased protein needs. Acute muscle-specific increases in muscle protein balance last for up to 48 h following resistance exercise and provide cellular-level support for the idea that resistive exercise is anabolic per se and results in conservation of body protein and not increased loss (Phillips et al. 1997, 1999, 2002). Of note are some recent data showing that even short-lived, low-intensity, dynamic exercise (Sheffield-Moore et al. 2004), as well as prolonged, intense, dynamic exercise (Miller et al. 2005), is also stimulatory for protein synthesis, indicating that they too would provide an anabolic stimulus to hang on to muscle protein. The weight of evidence contained in these studies (Miller et al. 2005; Phillips et al. 1997, 1999, 2002; Sheffield-Moore et al. 2004) should not be underestimated in its support for the hypothesis that exercise, be it resistive or dynamic, would actually provide a stimulus to promote greater intracellular reutilization of amino acids arising from proteolysis. The end result is that exercise would actually lower, not raise, protein requirements (i.e., the protein needed to replace losses).

Dietary protein in conditions of energy restriction

With the publication of the new DRIs there came new recommendations to establish what are termed Acceptable Macronutrient Distribution Ranges (AMDRs). AMDRs have been established for carbohydrate, protein, total fat, linoleic acid, and α -linolenic acid (Institute of Medicine 2005). The AMDRs for carbohydrate, fat, and protein as a percent of total energy intake are 45%–65%, 20%–35%, and 10%–35%, respectively, for adults. This is an important and relevant difference of the new DRIs compared with the older RDA and Recommended Nutrient Intake (RNI) values into which no such flexibility of range was built (Health and Welfare Canada 1990; National Research Council 1989). It is interesting to find that a number of well-controlled studies have examined the impact of a higher-protein diet, most of which provided dietary protein within the AMDR, on weight loss and body-composition changes following energy restriction in obese individuals (Farnsworth et al. 2003; Foster et al. 2003; Johnston et al. 2004; Layman et al. 2003, 2005; McAuley et al. 2005; Noakes et al. 2005; Parker et al. 2002). A consistent finding was that higher-protein diets resulted in greater weight loss and a greater amount of that loss was accounted for by fat mass. By difference, therefore, higher-protein diets promoted a greater retention of lean body mass. Blood lipoprotein changes were variable, but in

almost every case changes in lipoprotein concentrations were similar with higher-protein diets as they were with lower-protein (most often higher-carbohydrate) diets. Interestingly, subjects on the higher-protein diets often reported greater satiety and overall satisfaction with their diets than their low-protein counterparts (Johnston et al. 2004; Layman et al. 2003, 2005). Since the goal of energy restriction in a clinical setting is loss of stored energy as fat, the significance of the greater fat loss seen in these studies is particularly noteworthy (Farnsworth et al. 2003; Foster et al. 2003; Johnston et al. 2004; Layman et al. 2003, 2005; McAuley et al. 2005; Noakes et al. 2005; Parker et al. 2002). Perhaps of equal significance to the greater fat loss in these studies is the preservation of lean mass while undergoing weight loss. Since skeletal muscle serves as the largest disposal site for post-prandial glucose (Zierath and Kawano 2003), it also appears to play a role in post-prandial lipemia (Petitt and Curerton 2003), and is the greatest determinant of our basal metabolic rate (BMR; (Johnstone et al. 2005)), maintenance of as much metabolically active skeletal muscle mass as possible would appear to have substantial implications for resisting weight gain.

Athletes have long recognized the performance advantage of maintaining high lean-to-fat mass ratio for almost any sport; hence, while the clinical implications of weight loss favouring preservation of lean mass are significant, the same could be said for those in the athletic realm. Layman et al. (2005) recently showed, using a 16 week randomized 2 × 2 blocked design trial of both exercise (5 d/week walking and 2 d/week resistive exercise) and diets of varying levels of protein (higher: 1.5 g protein·kg⁻¹·d⁻¹ vs lower: 0.8 g protein·kg⁻¹·d⁻¹), that the effect of higher dietary protein was as potent in terms of total weight and fat loss as the addition of exercise in women (body mass index = 33 kg·m⁻²) consuming 7.1MJ·d⁻¹. In fact, weight loss in the group that consumed higher protein and exercised was 9.8 kg and of that 96% was lost from the fat compartment, the result being a reduction in their percentage body fat by almost 6%. By contrast the group that consumed a lower protein diet and did not exercise, a strategy tried by many when attempting to lose weight, lost 7.8 kg; however, only 64% of that loss was fat, meaning that this group also lost 2.7 kg of lean mass. Such findings may not surprise a number of athletes who, through trial and error, have reached the same conclusion, which is that to promote the greatest fat mass loss but avoid lean mass loss during times of caloric deprivation one must exercise and consume more protein. Presumably, given the anabolic nature of resistive exercise (Biolo et al. 1995, 1997; Phillips et al. 1997, 2002), this mode of exercise would provide the most powerful stimulus to retain lean body mass. Indeed, in the fasted state, muscle protein balance is significantly less negative for up to 48 h following an isolated bout of resistance exercise (Phillips et al. 1997), showing just how powerful a single bout of resistive exercise can be as a stimulus to conserve muscle protein.

Mechanisms of action

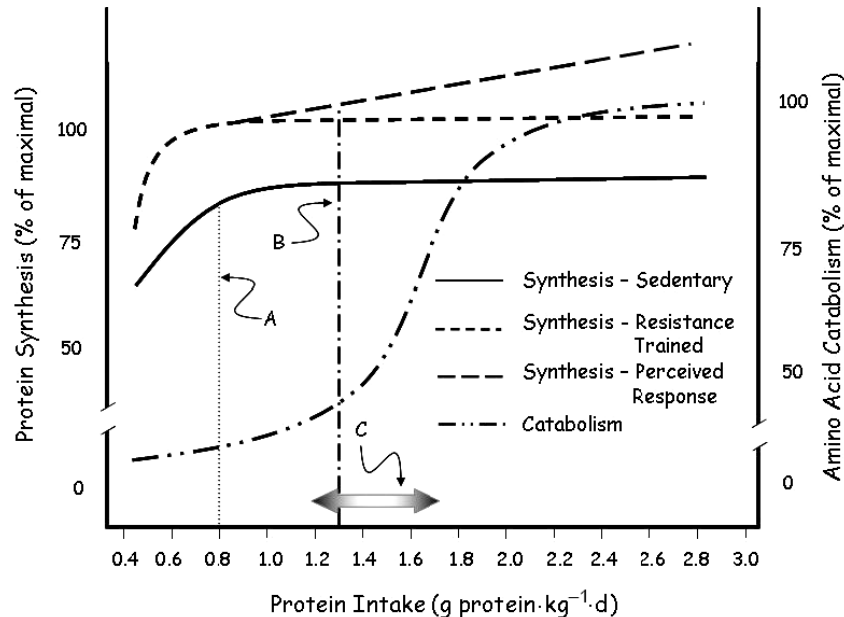
Why then are higher-protein diets more effective than lower-protein diets in promoting weight loss and particularly fat loss? In a meta-analytic review, Buchholz and Schoeller

(2004) concluded that “Diets high in protein and (or) low in carbohydrate produced an approximately equal to 2.5-kg [or] greater weight loss [of body mass] after 12 w[ee]ks of treatment. Neither macronutrient-specific differences in the availability of dietary energy nor changes in energy expenditure could explain these differences in weight loss.” In the final analysis, these authors concluded that there is an amount of energy expended on a daily basis that is greater with high-protein diets that cannot be satisfactorily accounted for by either the increased thermic effect of protein as a macronutrient (vs either carbohydrate or lipid) nor by any disproportionate activation of inefficient energy-consuming metabolic pathways specific to protein consumption. Others have presented contrary arguments stating that there is evidence that higher protein diets would result in greater fluxes through metabolically inefficient metabolic pathways (Fine and Feinman 2004). However, it has been argued that the magnitude of such an effect is insufficient to account for the differences seen in total weight loss (Buchholz and Schoeller 2004).

What is likely true with higher-protein diets is that even when a person is in an energy deficit the metabolic requirement for protein would be reduced somewhat, initially due to adaptive and ultimately due to accommodative mechanisms (Millward 2004a; Millward and Jackson 2004). At the same time, it appears that a higher protein intake is associated with retention of lean mass even while persons are in an energy deficit (Farnsworth et al. 2003; Foster et al. 2003; Johnston et al. 2004; Layman et al. 2003, 2005; McAuley et al. 2005; Noakes et al. 2005; Parker et al. 2002). Even in the face of consumption of protein above requirement levels during energy deficit, excess amino acids, once deaminated, produce carbon skeletons that would be oxidized, but that are ultimately very poor lipogenic substrates; in fact, only leucine and lysine as purely ketogenic amino acids (i.e., yielding acetoacetyl CoA) could likely support significant lipogenesis. Simply put, it is very metabolically difficult to turn excess protein into fat. A very interesting question is whether the metabolic advantage seen with higher than recommended protein intakes when people are in energy deficit transfers over to situations of energy balance? In other words, could someone simply shift their macronutrient ingestion ratio from a relatively high to a lower carbohydrate-to-protein ratio and achieve fat mass loss? Clearly, from a purely thermodynamic point of view, such a change would seem unlikely; however, as discussed by Fine and Feinman (2004), there is a theoretical basis for how an increase in protein consumption results in metabolically wasteful pathways. Hence, such an approach, even in persons in true energy balance, could result in an increased energy expenditure and hence a relatively slow weight loss.

It is also possible that certain classes of protein may confer an advantage during energy restriction in terms of their capacity to induce weight loss. Zemel (Zemel 2004) reported that a whey protein-derived angiotensin-converting enzyme (ACE) inhibitor synergistically enhanced the effect of dietary calcium on fat loss in energy-restricted aP2-*agouti* transgenic mice, which are mice that exhibit a pattern of obesity gene expression similar to humans (Shi et al. 2001). Interestingly, calcium and an ACE inhibitor were not as ef-

Fig. 2. Theoretical relationship between habitual protein intake and maximal functioning of protein synthetic processes for all body proteins in sedentary individuals (solid line), resistance-trained athletes (short dashed line), and the perceived relationship between dietary protein intake and maximal functioning of synthesis of body proteins in resistance-trained athletes (long dashed line), as well as the relationship between dietary protein intake and amino acid catabolism, and ultimately urea synthesis (dashed line with double dots). (A) Dietary protein RDA. (B) Estimated safe protein intake for resistance-training athletes (Phillips 2004). (C) Range of protein intakes at which adaptive metabolic advantage, including enhanced fat loss and retention of lean mass during energy restriction, of higher dietary protein intakes might be seen.



fective as either milk or whey in reducing the mass of stored fat during energy deficit (Zemel 2004). The data of Zemel (2004) point to an interesting link between whey protein-derived peptides and fat loss. While Zemel attributes ~40% of an enhanced weight loss with dairy product consumption to calcium and a modulatory role for 1,25-dihydroxyvitamin D (Xue and Zemel 2000; Zemel 2004), recent work reveals that whey-derived peptides may also be playing an integral role in promotion of fat loss. Certainly, a unique aspect of whey protein would be in its ability to support lean mass retention during energy restriction, due to its high essential and branched chain amino acid content and particularly its leucine content, as well as other bioactive peptides. Clearly, more research is needed regarding dairy protein, and whey protein in particular, during energy restriction to ascertain how a diet high in these constituents may enhance fat loss, particularly from central adipose stores (i.e., trunk fat) (Zemel et al. 2004).

Layman and Walker (2006) have put forth the hypothesis that it is the leucine content of the higher-protein energy-restricted diets that is important in maintaining lean mass and promoting fat loss. They propose that a diet high in leucine content, mainly through consumption of high-quality proteins during caloric restriction, would promote increased muscle protein synthesis and in doing so would promote retention of muscle protein. Interestingly, leucine infusion (3.5 g over 4 h) has been shown to reduce urinary nitrogen loss in fasting obese subjects (Sherwin 1978). Nevertheless, more work obviously remains to be done in this area to establish how higher-protein diets are able to induce greater fat loss and lean mass retention.

Dietary protein in athletes: requirements to advantage

How then can the assertion that exercise may act as a conservatory stimulus to retain amino acids and thus muscle protein be reconciled with data in which a higher-protein diet appears to be advantageous? Figure 2 is an attempt to show how this might come about.

There exists good evidence to suggest that both endurance- and resistance-based exercise can stimulate muscle protein synthesis (MPS) (Biolo et al. 1995; Miller et al. 2005; Phillips et al. 1997, 1999, 2002; Sheffield-Moore et al. 2004; Welle et al. 1995, 1999), which would act as an underlying basis for why exercise would be a protein-conserving stimulus. Although one can argue that muscle protein breakdown (MPB) is also elevated, in studies in which both MPS and MPB have been measured, the rise in synthesis has been shown to be consistently greater in magnitude than any rise in breakdown (Biolo et al. 1995; Miller et al. 2005; Phillips et al. 1997, 1999, 2002; Sheffield-Moore et al. 2004; Welle et al. 1995, 1999). In addition, urinary 3-methylhistidine excretion was shown not to rise even in the face of substantial increases in MPB (Phillips et al. 1997), indicating that even if proteolysis is elevated it is not due to substantial degradation of actin or myosin.

It is becoming clearer that higher-protein diets spare muscle protein and enhance fat loss during periods of energy restriction (Farnsworth et al. 2003; Foster et al. 2003; Johnston et al. 2004; Layman et al. 2003, 2005; McAuley et al. 2005; Noakes et al. 2005; Parker et al. 2002). With these results in mind it would appear to be wise to counsel both ath-

letes and patients for whom weight loss is a desired goal that up to 35% of their energy can come from protein and that this may result in a metabolic advantage in terms of the change in body composition achieved during energy restriction.

What must be made clear, however, is that 35% of an energy-restricted diet for an obese female (100 kg) consuming only 7 MJ·d⁻¹ (~1700 kcal·d⁻¹) would amount to ~150 g of protein or 1.5 g protein·kg⁻¹·d⁻¹. An athlete (e.g., a 20-y-old male hockey player) who may weigh closer to 90 kg and is consuming, while still being energy restricted, something closer to 10.4 MJ·d⁻¹ (~2500 kcal·d⁻¹) would be getting 219 g or 2.4 protein·kg⁻¹·d⁻¹ (close to the 1 gram protein per pound (lb) of body mass often recommended in magazines), assuming 35% of his total energy were from protein. If the same young hockey player were to consume 20% of his energy as fat he would have a displacement of dietary carbohydrate by protein and would only be getting 280 g of carbohydrate (3.1 g carbohydrate·kg⁻¹·d⁻¹), which is well below what is recommended for optimal athletic performance (Burke et al. 2004). This simple example highlights a pitfall for athletes who, although they may be seeking a lean physique, adopt a diet that is simply not going to allow them to perform over the long-run owing to incomplete muscle glycogen restoration (Burke et al. 2004). It is also quite apparent that at some point the benefit associated with a high-protein diet would have to diminish and result only in elevated blood urea and amino acid oxidation (i.e., a stimulation of amino acid breakdown and use of amino acids as fuel), as well as incomplete glycogen restoration. At this point, the performance-oriented utility of consuming higher protein intakes would be lost, at least for some athletes. However, the anecdote is very powerful in athletic circles and is proportional in its power based on the success of the athlete delivering it. Thus, it would take only one successful athlete to promote the idea that they won while consuming a particular diet for the practice to take hold. One question that athletes often fail to consider when adopting a new dietary regime is whether the diet works because of, or in spite of, what they are consuming. In fact, it has been shown that a number of athletes consume suboptimal carbohydrate intakes despite their elite status (Burke et al. 2001*b*), primarily due to their preoccupation with body mass and body fat. However, it is this author's opinion that athletes would likely tolerate all manner of diets if they believe it will enhance their performance.

The pitfalls of consuming a higher-protein diet and the potential for increased amino acid oxidation and loss of nitrogen between meals is an argument consistently put forth by Millward (e.g., Millward 2004*b*). However, many athletes, particular strength-training athletes and those seeking gains in lean body mass, will consume protein far above requirement levels (which may actually be lower owing to the anabolic nature of exercise) in the hopes that the extra protein will enhance protein synthesis and ultimately lead to a greater lean mass accretion. Some studies have shown that protein supplementation during intensive training can bring about greater gains in lean mass (Burke et al. 2001*a*; Deibert et al. 2004; Demling and DeSanti 2000), but a lack of strict controls and a fully randomized design make it difficult to draw a solid conclusion on this point. Of relevance, an opti-

mal dose of protein to achieve maximal muscle protein synthesis and hence muscle mass gains with resistance training is still unknown. Cuthbertson et al. (2005) recently reported that an oral dose of 10 g of essential amino acids maximally stimulated muscle protein synthesis in young individuals at rest. Considering that exercise per se is anabolic and acts as an independent stimulus for protein synthesis it is likely that an optimal dose of protein to maximize the anabolic response would be even less than 10 g. More to the point, once an increase in muscle mass is attained a high-protein diet would appear to be even more unnecessary.

During periods of energy restriction it does appear beneficial to consume protein above current requirement levels, although while in energy deficit the surfeit protein would be directed toward lean mass maintenance rather than gains. To date, one study has reported that muscle mass gains can occur while in a substantial exercised-induced energy deficit (Demling and DeSanti 2000), whereas another reported that higher protein could only maintain muscle mass (Deibert et al. 2004). Thermodynamically, tissue protein accretion is an energy requiring process; hence, the results of Demling and DeSanti (2000) are at odds with the concept that substantial muscle growth can be achieved when an overall energy deficit is in place. For skeletal muscle accretion to occur, in the face of energy deficit, it would require that energy would have to be preferentially directed toward muscle protein anabolism during a time when hormonally, and energetically, catabolism is favoured. Clearly, further work needs to be done on this topic, particularly in high-risk populations such as obese patients and those with type 2 diabetes or pre-diabetes for whom lean mass retention, and potentially gain, during weight (i.e., fat) loss would be far more beneficial than simply losing body mass, which would also include lean mass.

Summary

Available evidence suggests that protein requirements are not likely elevated, if they are elevated at all, by substantial amounts in persons completing exercise of either a dynamic or resistive nature. Ultimately, a debate on protein requirements appears to be moot for most athletes anyway, since their habitual intakes, particularly those of males, far exceed the RDA and even the most liberal estimates of requirement, which when estimated from existing nitrogen balance data in strength-trained athletes is ~1.3 g protein·kg⁻¹·d⁻¹ (Phillips 2004) or ~1.1 g protein·kg⁻¹·d⁻¹ in endurance-trained athletes (Tarnopolsky 2004). Accumulating evidence suggests that energy-restricted higher-protein diets may offer some benefit in terms of promoting fat loss while maintaining lean mass. It may be that higher-quality proteins consumed during such an energy-restricted period offer a further advantage owing to their high leucine content; however, additional work is required to confirm this thesis.

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