Beyond the Zone: Protein Needs of Active Individuals

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There has been debate among athletes and nutritionists regarding dietary protein needs for centuries. Although contrary to traditional belief, recent scientific information collected on physically active individuals tends to indicate that regular exercise increases daily protein requirements; however, the precise details remain to be worked out. Based on laboratory measures, daily protein requirements are increased by perhaps as much as 100% *vs.* recommendations for sedentary individuals (1.6–1.8 *vs.* 0.8 g/kg). Yet even these intakes are much less than those reported by most athletes. This may mean that actual requirements are below what is needed to optimize athletic performance, and so the debate continues. Numerous interacting factors including energy intake, carbohydrate availability, exercise intensity, duration and type, dietary protein quality, training history, gender, age, timing of nutrient intake and the like make this topic extremely complex. Many questions remain to be resolved. At the present time, substantial data indicate that the current recommended protein intake should be adjusted upward for those who are physically active, especially in populations whose needs are elevated for other reasons, e.g., growing individuals, dieters, vegetarians, individuals with muscle disease-induced weakness and the elderly. For these latter groups, specific supplementation may be appropriate, but for most North Americans who consume a varied diet, including complete protein foods (meat, eggs, fish and dairy products), and sufficient energy the increased protein needs induced by a regular exercise program can be met in one's diet.

Key teaching points:

- Dietary protein needs for physically active individuals have been controversial for many years.
- Generally, athletes have felt their needs are substantially greater than the recommendation from scientists - both opinions could be correct as the latter is based on data from essentially sedentary subjects.
- Recent scientific study suggests a variety of factors need to be considered when determining protein requirements, including but probably not limited to total energy intake, carbohydrate availability, exercise intensity, exercise duration, exercise type, dietary protein quality, training history, gender, age and timing of nutrient intake.
- These studies indicate that for physically active individuals daily protein intake needs could be as high as 1.6–1.8 g/kg (about twice the current recommendation).
- Despite these increased protein needs, assuming energy intake is sufficient to match the additional expenditures of training and competition (which can be excessive), special protein supplementation is unnecessary for most who consume a varied diet containing complete protein foods (meat, fish, eggs and dairy products).
- Those at greatest risk of consuming insufficient protein are those whose lifestyle combines other factors known to increase protein needs with a regular exercise program, e.g., those with insufficient energy intake (dieters), growing individuals, vegetarians, the elderly, those with muscle diseases and so on.

INTRODUCTION

In recent years, the multiple and varied health benefits resulting from regular physical activity have become well documented; as a result, recommendations for increasing one's exercise level are becoming commonplace [1,2]. Although athletes, especially those heavily involved with strength training, have long believed that their protein intakes must be much greater than for those who are sedentary, this opinion is derived via nonscientific means. In contrast, the current recommended dietary allowance (RDA) for protein does not recognize any increased protein need for a physically active lifestyle [3]. However, even this scientific recommendation could be incorrect, as it is based on data collected from physically inactive or, at best, minimally active individuals.

Throughout most of the 20th century, it has been assumed

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that physical exercise was an insufficient stimulus to alter protein needs significantly, even though this question had not been examined systematically in the scientific literature. In light of the new physical activity recommendations, it is particularly important to know if regular exercise increases dietary protein needs because, if so, following these guidelines could lead to significant health problems related to sub-clinical/clinical protein deficiency.

Perhaps also contributing to the debate among scientists and athletes regarding dietary protein need is the fact that the scientific studies have concentrated almost exclusively on laboratory measures (primarily nitrogen balance), yet these may not relate directly to exercise performance, which is, of course, the main focus of the athletes. Further, although not always appreciated, it is possible that, even if a measure like nitrogen balance does not indicate an increased protein requirement, exercise performance could still be enhanced by a greater protein intake, i.e., the additional protein might alter a metabolic process enhancing energy utilization for endurance performance or could stimulate anabolism resulting in greater muscle mass and/or strength gains. Hence the current recommended protein intake could be sub-optimal for those who regularly exercise. Fortunately, there is substantial recent scientific information collected on physically active subjects (completed after the current US recommendations were published [3]), and much of this suggests that regular physical activity can increase protein needs. These studies form the main focus of this review. Finally, this area of research has become far more popular, and, as more information becomes available, the importance of related/influencing factors, including type of protein or amino acids consumed, whether taken as a bolus or in multiple intakes, when consumed throughout the day or relative to the exercise sessions, age/gender/other foodstuff interactions, as well as a variety of other factors, are beginning to come into focus.

FACTORS WHICH APPEAR TO AFFECT DIETARY PROTEIN NEED

Energy (Food) Intake

It has been known for about half a century that inadequate energy intake leads to increased dietary protein needs [4], presumably because some of the protein normally used to synthesize both functional (enzymatic) and structural (tissue) protein is utilized for energy under these conditions. Apparently, this effect on protein need is similar when the energy deficit is caused by increased energy expenditure (exercise) [5,6]. In fact, this effect could be even more dramatic in those who are physically active, as protein needs are likely already increased in order to maintain a greater protein synthetic rate due to the presence of greater absolute tissue (strength athletes) or enzyme (endurance athletes) levels. In addition, there appears to be a gender difference in one's ability to increase food intake adequately with chronic high intensity exercise. Perhaps for reasons related to maintenance of reproductive function in times of energy deficit, females are better able to preserve functional tissue than males whenever energy intake is low [7–11]. Although this is of obvious benefit in a starvation situation, for physically active females it often results in undereating relative to energy expenditure [12–16, Fig. 1). As a result, females are able to maintain body mass at energy intakes below the point where their male counterparts lose a significant percentage of their mass. This may occur via some kind of down-regulation of metabolism in females. Although not well studied, this phenomenon could lead to a variety of nutrient deficiencies because, as overall energy intake is reduced, so is intake of most of the indispensable nutrients [15]. The details of how this might alter protein need in men *vs.* women when energy intake is insufficient is an area that requires much more attention.

Carbohydrate Content

Carbohydrate availability to exercising muscle is critical for intense muscle contraction, as it is a more efficient fuel (produces more adenosine triphosphate per unit of oxygen) than both fat and protein. In combination with the fact that the total carbohydrate stores in the body can be depleted in a single exercise bout, this makes carbohydrate the single most important exercise fuel. As a result, carbohydrate has been studied to a much greater extent than either protein or fat. However, inadequate carbohydrate for muscle contraction is also critical because its availability is inversely related to the rate of exercise protein catabolism (Fig. 2 [17]). Therefore, daily carbohydrate intake is of great significance for physically active individuals. Moreover, physically active individuals need to be much less concerned about excess dietary carbohydrate intake resulting in surplus body fat storage (and associated adverse

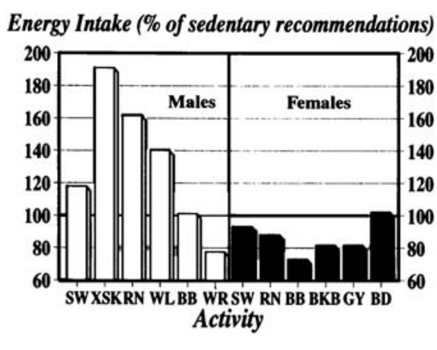

Fig. 1. Gender effects on energy (food) intake in physically active individuals (SW = swimmers, XSK = cross-country skiers, RN = distance runners, WL = weight lifters, BB = bodybuilders, WR = wrestlers, BKB = basketball players, GY = gymnasts, BD = ballet dancers). While men typically increase their energy intake appropriately for the increased expenditure of their activity (with the exception of bodybuilders and wrestlers), women routinely fail to do so. (Adapted from [12–16].)

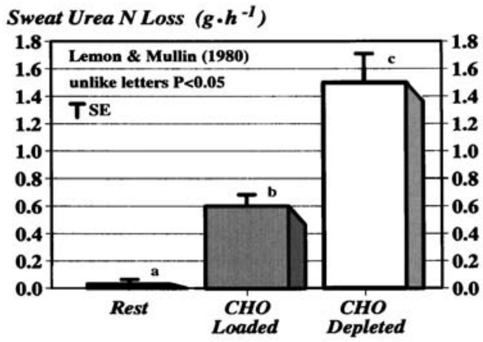

Fig. 2. Nitrogen excretion increases with prolonged, moderately intense exercise and especially so when carbohydrate stores are low. (Adapted from [17].)

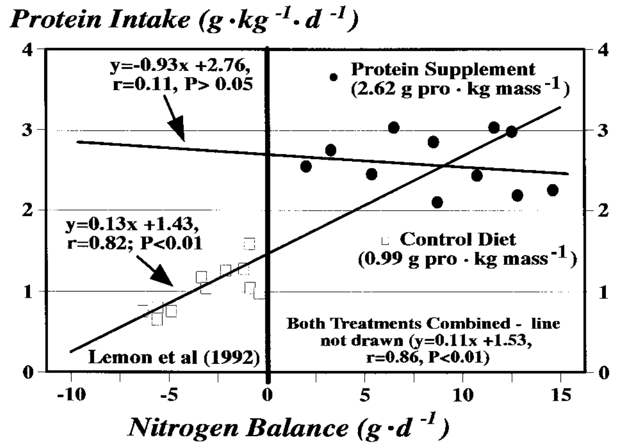

Fig. 4. Comparison of nitrogen balance (protein requirements) in individuals who are strength training with differing protein intakes. (Adapted from [23].)

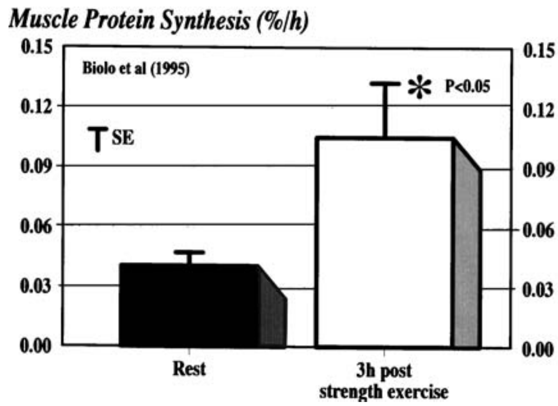

Fig. 5. Effect of a strength training session on muscle protein synthesis. (Adapted from [25].)

health effects) compared to their sedentary counterparts because this substrate is used to replenish carbohydrates stores depleted by exercise training/competition sessions. In fact, rather than over-consuming carbohydrate, athletes typically have great difficulty replenishing carbohydrate stores following exercise.

Exercise Intensity, Duration and Type

Increasing exercise intensity and duration, at least with aerobic (endurance) exercise, causes increased use of protein, presumably as an auxiliary fuel [18–21]. Based primarily on nitrogen balance experiments, this results in an increased daily protein need of about 50% to 75% (1.2–1.4 *vs.* 0.8 g/kg) when compared to inactive individuals (Fig. 3 [22]). Although heavy resistance (strength) exercise appears to increase protein need by about 100% (1.6–1.8 *vs.* 0.8 g/kg) based on nitrogen balance experiments (Fig. 4 [23]), isotope tracer studies have revealed that the underlying mechanism is not increased fuel use [24]. Rather, it is the result of changes in muscle protein synthetic rate (Fig. 5 [25]) and the need to maintain a greater overall muscle mass [26]. If so, this raises an interesting question about possible interacting effects of other compounds and whether some might be able to potentiate the already powerful anabolic stimulus of strength exercise.

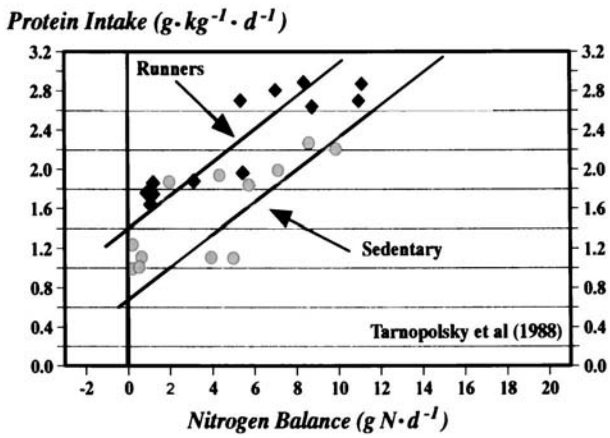

Fig. 3. Comparison of nitrogen balance (protein requirements) in distance runners *vs.* sedentary subjects. (Adapted from [22].)

Recently, daily supplementation of creatine (~ 285 mg/kg), a component of meat and fish, for as brief a time interval of three to five days has been shown to enhance intense exercise performance, especially when the exercise is repeated with brief recovery intervals [27]. The underlying mechanism of action is thought to involve additional phosphocreatine storage in muscle, increased regeneration of phosphocreatine during any brief recovery intervals and/or by buffering some of the hydrogen ions formed during intense anaerobic exercise (Fig. 6). In our laboratory, we have seen this effect in both recreational and elite athletes and have even observed a residual performance effect lasting for at least four weeks following cessation of supplementation (Fig. 7 [28]). Moreover, we have recently measured (Table 1) greater gains in both muscle mass and strength in subjects training with creatine and protein than with protein alone [29, 30]. Although strength athletes can

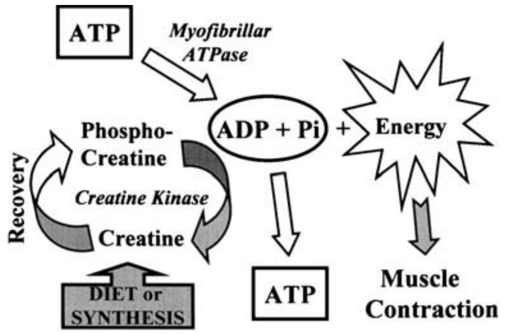

Fig. 6. Schematic representation of how creatine could enhance adenosine triphosphate availability and, consequently, intense exercise performance.

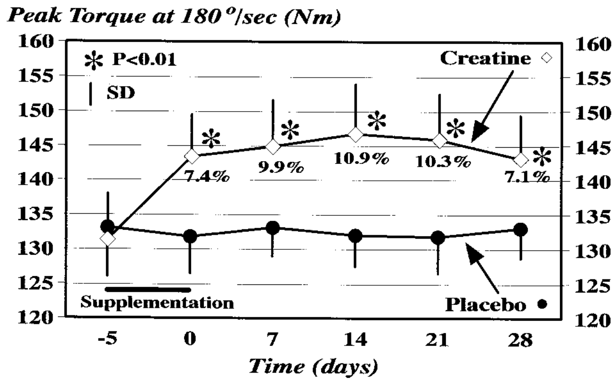

Fig. 7. Effects of brief (5 day, 20 g/day) creatine supplemetation on intense exercise performance (isokinetic knee extension [Nm] at 180°/sec) over the subsequent 4 weeks. (Adapted from [28].)

increase muscle growth with supplemental protein, this effect seems to attain a plateau at protein intakes (1.4 g/kg) far below intakes typical of experienced bodybuilders (Fig. 8 [26]). Perhaps these preliminary data indicate that the ceiling effect of supplemental protein observed in strength athletes in the laboratory studies (around 1.4 g protein/day) can be further raised if combined with creatine. If so, this could explain, at least in part, the opinion of strength athletes about protein needs because, even before the relatively recent popularity of creatine supplementation, strength athletes have consumed routinely huge amounts of meat and fish. Obviously, it is not possible to consume sufficient meat/day to equal the creatine intake of most studies demonstrating ergogenic effects (it would require about 4–5 kg). However, it is interesting to note that much more modest creatine supplementation (3 g/day) over a longer time period (4 wk) can result in similar muscle creatine stores [31]. Perhaps the intake of creatine (and/or some other compound in meat and fish) in combination with the associated large amino acid intake can explain why strength athletes experience gains in mass and strength with protein intakes far exceeding where the laboratory studies show no further gains. This hypothesis needs to be examined.

Protein Quality

It is well known that humans can synthesize only about 50% of the necessary amino acids that make up the proteins in our bodies. Therefore, if the remaining amino acids (called indispensable or essential) are not consumed in sufficient quantities, protein production is affected adversely. The quality of protein in a food is determined by its indispensable amino acid content (Table 2 [32]). Some foods contain all of these indispensable amino acids and in amounts sufficient to maintain protein synthesis, while others are lacking in at least one amino acid. The former are called complete protein foods and include such foods as dairy products, eggs, meat and fish, while the latter include grains, vegetables and fruits. Although it is also possible to obtain sufficient indispensable amino acids from a diet that excludes complete protein foods entirely by combining grains, vegetables and fruits, this requires some knowledge of which foods to combine. As a result, vegetarians, especially those that exclude eggs and dairy products, when they adopt a physically active lifestyle constitute a group that is likely at greater risk for insufficient dietary protein intake. Moreover, it has been shown, at least in 59 to 69 year-old men, that strength training produced greater muscle mass gains with a meat-containing diet in comparison to a lactovegetarian diet [33]. These data suggest that type of protein may play an important role in muscle growth with strength training. Whey protein, especially whey protein isolates or hydrolyzed whey peptides, is widely promoted to strength athletes as being perhaps the best protein based on its high bioavailability and its content of several critical amino acids, i.e., glutamine, leucine, isoleucine and valine. We attempted to assess whether a whey protein supplement could promote greater gains in muscle size and strength with weight training in young men *vs.* casein, soy or maltodextrin [34]. In this study all groups received a daily 0.7 g/kg supplement on top of their normal daily protein intake which was 1.4–1.6 g/kg and, although all groups gained significantly in both strength and size, there was no difference among the groups. The obvious conclusion is that protein type does not affect strength/size gains with strength exercise but, because the response of the maltodextrin group was of the same magnitude, it could be that the pre-supplementation protein intake was already sufficient to maximize muscle growth. Additional study is needed to clarify these possibilities. Whether combining dietary proteins can further stimulate muscle growth is another possibility which should be assessed because there is evidence that, due to differing physiochemical properties, whey protein amino acids enter the blood stream following ingestion faster than casein (major milk protein), which produces a significantly lower but more prolonged increase in blood amino acids [35].

Training History

With regular endurance exercise (training) there appears to be an increase in amino acid oxidation [36–38], likely due to

Table 1. Strength (Number of Repetitions at 80% of the Maximum Weight That Could Be Lifted One Time for the Double Leg Press [1-RM]) and Arm Muscle Volume (10, 2 mm Contiguous Magnetic Resonance Slices) Changes with Seven Weeks of Strength Training Combined with a Daily Supplement of Creatine+Protein vs. Protein or Creatine Alone [29,30].

	Arm Volume		Leg Press	
	Baseline	Post Training (mL)	Baseline	Post Training (# rep at 80% 1-RM)
Creatine + Protein	103.1 ± 5.9	116.7 ± 6.8[ab]	10.0 ± 1.8	40.0 ± 3.9[ab]
Protein	86.8 ± 4.9	94.4 ± 4.2[a]	7.7 ± 0.7	23.9 ± 1.8[a]
Creatine	94.2 ± 4.1	109.9 ± 3.0[ab]	11.9 ± 1.5	29.8 ± 3.6[ab]

[a] $p<0.05$ *vs.* baseline
[b] $p<0.05$ *vs.* protein alone

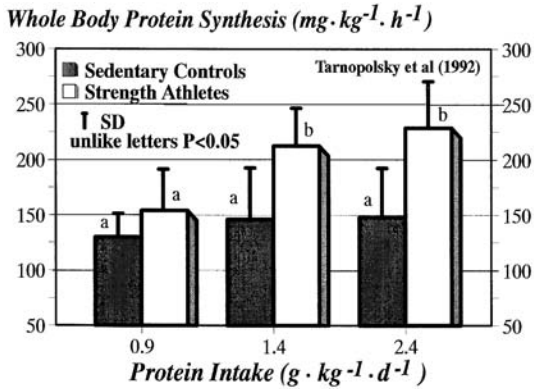

Fig. 8. Effect of increasing protein intake on protein synthesis in strength athletes *vs.* controls. (Adapted from [26].)

Table 2. Protein Digestibility-Corrected Amino Acid Score [32].

Protein Source	Score
Egg white	1.00
Casein (milk)	1.00
Isolated soy protein	1.00
Beef	0.92
Kidney beans	0.68
Rolled oats	0.57
Lentils	0.52
Whole wheat	0.40

changes in branched-chain oxoacid dehydrogenase activity [38]; however, more study is required, as at least one study doesn't support these data [39] and there is no apparent explanation for these contradictory observations. With strength training there is also some confusion. Some initial work indicated that protein needs to support the increased muscle growth at the initiation of a bodybuilding program might exceed those necessary to maintain the greater muscle mass later in training [22], while other studies suggest that the need for protein remains at similar levels for experienced strength athletes [23,26]. Recently, at least with eccentric exercise, it has been shown that, although muscle protein synthesis can be stimulated with acute strength exercise in both resistance-trained and untrained subjects, protein breakdown was greater in the latter group [40]. These data provide mechanistic support for the earlier observation that a single eccentric bout reduces subsequent muscle damage and pain [41] and may indicate that initial increased protein needs with strength training are reduced with training experience. Before specific needs of experienced *vs.* novice strength athletes can be determined, more work is necessary to ascertain exactly how these data all fit together.

Gender

Most of the study of protein needs in physically active individuals has been completed utilizing male subjects; however, there are data suggesting that protein utilization in women, at least with endurance exercise, is significantly less than in men [42,43]. Also, there are *in vitro* [44] and *in vivo* [45] results indicating protein utilization with exercise is greater in male than female rodents. The mechanism of action could involve gender-specific hormonal responses that favor fat metabolism in women (resulting in a reduced reliance on both carbohydrate and protein [46]) or that protect the muscle membrane from exercise-induced damage [47,48]. The effects of strength training on protein requirements in female subjects has not yet been studied systematically. Consequently, it remains to be determined whether gender differences exist relative to the quantity of dietary protein required to maximize muscle growth.

Age

Sarcopenia is a term used to describe the loss of skeletal muscle mass with advancing age. Functionally, as well as from a health care point of view, this is of considerable significance because it is associated with weakness and decreased independence. This will be especially true over the next 20 to 30 years given the large numbers of the baby boomer generation rapidly approaching the point where sarcopenia will begin to affect them. Although part of this muscle loss is likely the result of reduced activity, physiological/biochemical processes are also involved, as indicated by the 30% reduction in myofibrillar protein synthesis in individuals over 60 years of age (Fig. 9

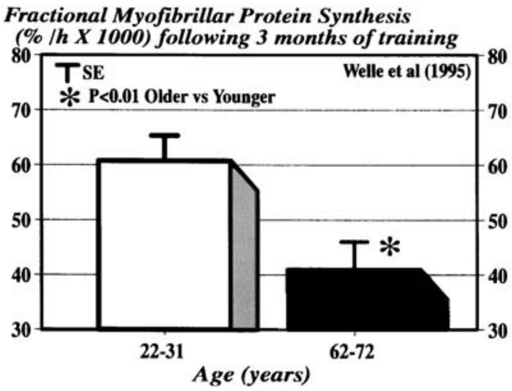

Fig. 9. Effect of age on muscle protein synthesis. (Adapted from reference 49.)

[49]). Further, muscle performance/function improves with strength exercise even into the tenth decade of life [50], and this is not due to improved neurological function alone, as three months of regular strength exercise can increase mixed muscle protein synthesis even in the frail elderly (76 to 92 year-old men and women) [51]. Typically, nutrient intake is less than ideal in the elderly and, although short term (10 day) energy and protein supplementation can enhance protein synthesis and fat-free mass in 60 to 90 year-old men and women [52], whether nutritional supplementation might enhance further muscle growth with strength exercise in the elderly is an interesting possibility. One study observed that a 360 kcal (60% carbohydrate, 23% fat, 17% protein) supplement in combination with a 10-week strength program increased both muscle strength and size more that the same training without supplementation in 72 to 98 year-old men and women [53]. In contrast, acute (one-day) feeding of protein at 0.6, 1.2, or 2.4 g/kg did not affect myofibrillar protein synthesis following a very brief (three-session) knee extension program [54]. Although this could implicate energy rather than protein as the major anabolic stimulus, it is likely the answer to these contradictory data is far more complicated. For example, the acute *vs.* chronic exercise stimulus or the length of the time on the treatment diets could both be important. Finally, at least in older women (60 to 73 years) over a 14-day time period, a pulse intake of protein (7% at 0800, 79% at 1200, 14% at 2000) *vs.* spread (25% at each of 0800, 1200, 1600, 2000) produced a greater gain in fat free mass [55]. Consequently, mass of protein consumed and/or timing of intake (see below) may also be critical, although this latter study did not involve any exercise and, therefore, may apply only to a sedentary individuals.

The other end of the age continuum is also of interest because dietary protein needs are known to be greater due to growth [3]. Although not systematically investigated, it is possible that regular physical activity could further increase protein requirements for this population [56–58]. For similar reasons, women who actively exercise during pregnancy are another high risk group where supplementary protein/energy may be advantageous.

Timing of Macronutrient Intake

It is clear that carbohydrate intake immediately following glycogen-depleting exercise can enhance subsequent muscle glycogen resynthesis when compared to the same intake several hours later [59]. Similarly, it could be possible to stimulate muscle growth (by minimizing degradation and/or maximizing synthesis) via carbohydrate or amino acid ingestion following a strength exercise session [60,61]. This is likely due to insulin-stimulated [62,63] changes in muscle amino acid uptake and protein synthesis (Fig. 10 [62]). Further, it appears that the nonessential (dispensable) amino acids are unnecessary (Fig. 11 [62]). We know that a strength training session affects both muscle protein degradation and synthesis (Fig. 12), but the precise magnitude of the responses and the time course is yet to be determined [64,65]. As these responses become clear, it might be possible to make very precise recommendations to maximize the anabolic stimulus following strength training. Clearly, this would benefit a variety of populations in addition to athletes, i.e., those who have lost muscle function due to disease, disuse and the like. The latter could be very critical relative to both quality of life and even to health care costs as the large numbers of baby boomers pass into the senior age groups.

SUMMARY

A variety of factors interact to increase dietary protein needs of individuals who exercise regularly. Although future study will need to determine precise recommendations, current research indicates that as long as energy intake is adequate a daily protein intake of 1.2–1.4 g/d for individuals participating in regular endurance exercise and 1.6–1.8 g/kg for their counterparts involved in strength exercise (Fig. 13) should be sufficient. To ensure these increased needs are met, care should be taken to consume a diet containing adequate energy and a selection of high quality protein foods, i.e., dairy products, eggs, meat, fish and soy products. Select populations may be at increased risk of not consuming sufficient protein due to increased requirements for a variety of

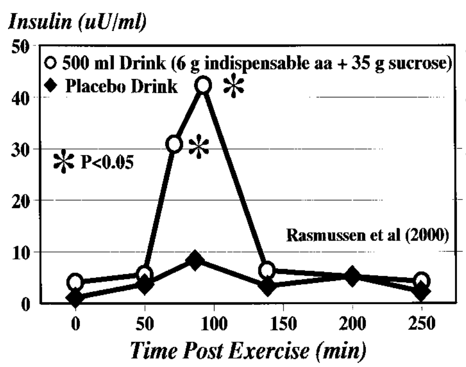

Fig. 10. Effect of indispensable amino acid intake following strength exercise on insulin release. (Adapted from [62].)

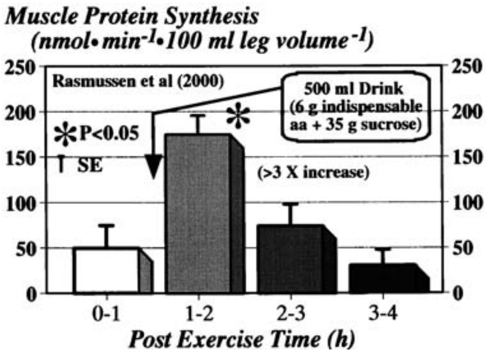

Fig. 11. Effect on indispensable amino acid intake following strength exercise on protein synthesis. (Adapted from [62].)

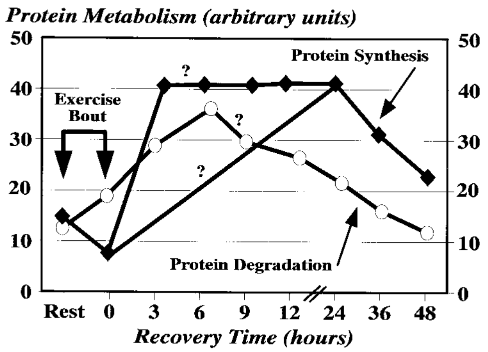

Fig. 12. Schematic representation of how time affects protein metabolism. (Adapted from [66].)

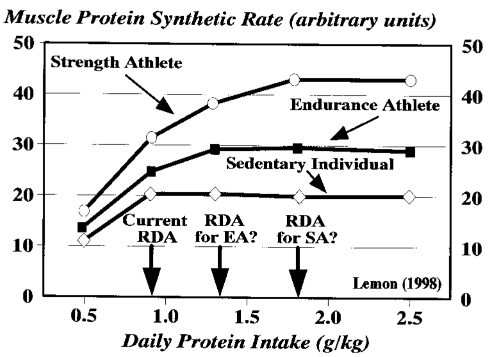

Fig. 13. Schematic representation of how exercise may alter protein requirements. (Adapted from [66].)

other reasons, i.e., unbalanced diet (vegetarians), inadequate energy intake (dieters or athletes with high energy expenditure, especially women), higher baseline requirements (those who are growing or the elderly) and so on. More study is necessary before all of this can be untangled.

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