

# DIETARY PROTEIN, AMINO ACID SUPPLEMENTS, AND RECOVERY FROM EXERCISE

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- The maximum daily protein requirement for endurance- or resistance-trained athletes is 1.2-1.7 g per kg body weight (0.55-0.77 g/lb). This requirement can easily be met through diet alone—without the use of supplements—provided that sound nutrition principles are followed and energy intake is sufficient to maintain body weight.
- Amino acids are always a minor source of fuel, usually accounting for less than 5% of total energy expenditure.
- If enough carbohydrate is ingested, i.e.,  $\sim 1.2 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$  ( $0.55 \text{ g}\cdot\text{lb}^{-1}\cdot\text{h}^{-1}$ ) in 15-30 min intervals during the first 2-5 h of recovery, protein supplementation does not further increase muscle glycogen replenishment. However, if no food or too little carbohydrate is consumed, ingestion of protein or specific amino acids during recovery from prolonged exercise may accelerate glycogen resynthesis.
- Ingesting a single drink containing  $\sim 0.1 \text{ g/kg}$  of essential amino acids during the first few hours of recovery from heavy resistance exercise will produce a transient, net positive increase in muscle protein balance. It is uncertain if ingesting amino acids immediately before exercise or ingesting carbohydrate along with amino acids, either immediately before exercise or during recovery, further enhances the rate of muscle protein buildup during recovery.
- Ingesting several doses of essential amino acids during recovery will promote a net “anabolic” environment over 24 h, but it remains to be determined if the acute effects of supplementation eventually lead to greater gains in muscle mass following habitual training.

**INTRODUCTION**

The topic of dietary protein and amino acid supplementation remains prominent and contentious in the field of exercise physiology. There is still no compelling scientific evidence to suggest that active individuals need to fortify their habitual diets with protein powders or amino acid supplements. However, there has

been debate recently regarding the potential for post-exercise nutrient intake—specifically, the timing and/or composition of protein/amino acid ingestion during recovery—to enhance anabolic processes in muscle after either acute or habitual exercise. Two areas that have received particular attention include possible alterations in rates of (1) muscle glycogen resynthesis after prolonged aerobic exercise and (2) muscle protein turnover after heavy resistance exercise. This brief review summarizes recent scientific literature on these topics and evaluates the various post-exercise nutrition strategies that have been advocated.

**RESEARCH REVIEW****How Much Protein Do Athletes Need?**

The current Dietary Reference Intake (DRI) for protein is  $0.8 \text{ g}\cdot(\text{kg body weight})^{-1}\cdot\text{d}^{-1}$  [ $0.36 \text{ g}\cdot(\text{lb body weight})^{-1}\cdot\text{d}^{-1}$ ] for persons over 18 years of age, irrespective of physical activity status. [DRIs are nutrient reference values established by scientists in the United States and Canada that are purported to meet the nutrient needs of 97-98% of the individuals in a particular group; DRIs replace the Recommended Dietary Allowance (RDAs) and Recommended Nutrient Intakes (RNIs) previously published by the U.S. National Academy of Sciences and the Canadian government, respectively.] However, in 2000 a joint position statement endorsed by the American College of Sports Medicine (ACSM), American Dietetic Association (ADA), and Dietitians of Canada (DC) (2000) concluded that protein requirements are higher in very active individuals and suggested that endurance athletes should consume 1.2 to  $1.4 \text{ g}\cdot\text{kg}^{-1}\cdot\text{d}^{-1}$  ( $0.55$  to  $0.64 \text{ g}\cdot\text{lb}^{-1}\cdot\text{d}^{-1}$ ), whereas resistance-trained athletes may need as much as  $1.6$  to  $1.7 \text{ g}\cdot\text{kg}^{-1}\cdot\text{d}^{-1}$  ( $0.73$  to  $0.77 \text{ g}\cdot\text{lb}^{-1}\cdot\text{d}^{-1}$ ). Although the contribution from amino acid oxidation to total energy expenditure during exercise is low ( $\sim 5\%$ ), endurance athletes may have an increased requirement due to high training volumes, whereas resistance-trained individuals may have chronically elevated rates of protein synthesis. From a practical perspective, the scientific controversy is rather meaningless, because the vast majority of athletes consume protein far in excess of any increased dietary requirement (Phillips, 2002; Rennie & Tipton, 2000; Tarnopolsky, 1999). Some individuals may need to monitor their food choices carefully (e.g., vegetarians athletes or those engaged in sports that favor a lean body mass), but very few athletes are at risk of protein deficiency, provided that energy intake is sufficient to maintain body weight and sound nutrition practices are followed, e.g., as outlined in the ACSM/ADA/DC Joint Position Statement (2000).

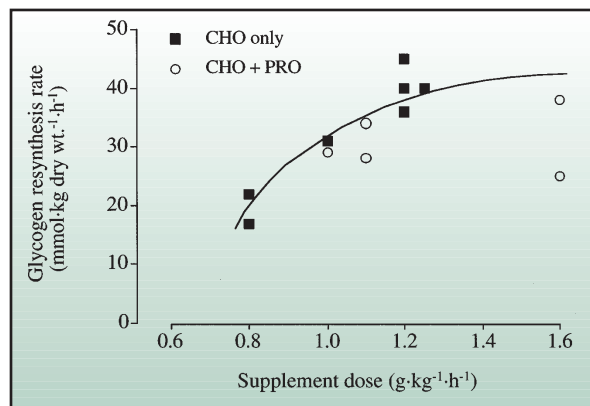
### Muscle Glycogen Resynthesis After Prolonged Exercise: Effect of Protein Ingestion.

Muscle glycogen is the predominant fuel catabolized for energy during heavy exercise, and the ability to rapidly replenish glycogen stores during recovery is an important concern for athletes, especially those who partake in exercise bouts of long duration or more than once a day. It is well known that carbohydrate (CHO) ingestion accelerates muscle glycogen resynthesis during the initial few hours of recovery (Ivy, 1998), but recent studies have examined whether co-ingestion of protein may augment this response. In the first study to examine this topic, Zawadski et al. (1992) reported that, when compared to CHO alone, the rate of glycogen resynthesis was 38% higher after 4 h of recovery in trained cyclists when they ingested  $\sim 0.3 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$  of a whey protein mixture in addition to  $\sim 0.8 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$  of CHO, immediately and 2 h following a 2-h exercise bout. The stimulatory effect of added protein was attributed to an increased rate of insulin secretion and presumably higher rate of muscle glucose uptake. However, a potential confounding factor in that study was that subjects consumed  $\sim 41\%$  more energy during the protein-supplemented trial.

Several recent studies reported no effect of protein supplementation on muscle glycogen resynthesis following exercise when total energy intake was kept constant (Carrithers et al., 2000; van Loon et al., 2000) or when protein was added to a CHO supplementation protocol that provided more CHO than the  $\sim 0.8 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$  given by Zawadski et al. (1992) (Jentjens et al., 2001; van Hall et al., 2000). The significance of controlling for total energy intake was highlighted in a study by van Loon et al. (2000) in which trained cyclists rode for 90 min and then ingested one of three solutions every 30 min in random order: (1) CHO at a rate of  $0.8 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ , (2) the same amount of CHO plus  $0.4 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$  of a protein solution, or (3) CHO at a rate of  $1.2 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ . After 5 h of recovery, there was no difference in muscle glycogen resynthesis between the latter two trials, suggesting that protein added to a CHO supplement was no more effective than additional CHO when the total energy value was maintained constant. Moreover, the glycogen resynthesis rates were more than double that of the control trial, which supplied only  $0.8 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$  CHO, suggesting that the amount and/or rate of CHO ingestion provided by Zawadski et al. (1992) may not have been optimal for maximizing muscle glycogen resynthesis. These conclusions were reinforced by van Hall et al. (2000), who demonstrated that additional protein ingestion—even though it tended to increase blood insulin—had no effect on leg glucose uptake or muscle glycogen resynthesis during recovery when CHO was consumed at a rate of  $1.25 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ . Thus, from a practical standpoint, it appears that protein ingestion *per se* or via augmented insulin secretion does not enhance the rate of muscle glycogen resynthesis when CHO is consumed in sufficient quantities, i.e.,  $=1.2 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$  in 15-30 minute intervals during the first 3-5 h of recovery from prolonged exercise (Figure 1).

In response to the “unequal energy” criticism of their group’s earlier paper (Zawadski et al., 1992), Ivy et al. (2002) reported that a CHO-protein supplement was more effective for the rapid replenishment of glycogen after exercise than a CHO supplement of equal energy content, but the effect could not be explained by differences in the plasma insulin response. The practical implications of the work of Ivy et al. (2002) are debatable, because the

timing and dose of CHO administered were similar to that provided by Zawadski et al. (1992), and others have shown that this protocol is less than optimal for achieving peak rates of muscle glycogen resynthesis (Jentjens et al., 2001; van Hall et al., 2000). However, from a basic science perspective, the results of Ivy et al. (2002) are consistent with studies showing that specific amino acids such as glutamine (Bowtell et al., 1999; Varnier et al., 1995) and possibly arginine (Yaspelkis & Ivy, 1999) may influence post-exercise glycogen resynthesis to a surprising extent, particularly in the absence of CHO intake.



**FIGURE 1.** Average rates of muscle glycogen resynthesis during 3-5 h of recovery from prolonged exercise when subjects were fed CHO or CHO+protein. Data from Carrithers et al. (2000), Jentjens et al. (2001), van Hall et al. (2000), van Loon et al. (2000), Zawadski et al. (1992). There appears to be no additional benefit of protein ingestion on glycogen resynthesis when CHO is consumed at an hourly rate  $>1.2 \text{ g/kg}$  of body weight.

### Muscle Protein Turnover After Resistance Exercise: Effect of Amino Acid Ingestion.

Rates of synthesis and breakdown of mixed proteins in muscle are acutely elevated following intense resistance exercise, but net balance of muscle protein is negative (i.e., breakdown exceeds synthesis) if subjects remain fasted (Phillips et al., 1997). However, amino acid ingestion alters this response, as first shown by Tipton et al. (1999), who had subjects consume 40 g of either mixed or essential amino acids in small doses during  $\sim 4.5 \text{ h}$  of recovery from heavy resistance exercise. Amino acid ingestion increased net leg muscle protein synthesis compared to a placebo drink; importantly, whereas net balance was negative during the placebo condition, this changed to positive (i.e., anabolic) following amino acid ingestion (Tipton et al., 1999).

It appears that a surprisingly small dose of essential amino acids can markedly stimulate muscle protein anabolism during recovery. For example, Rasmussen et al. (2000) showed that, when compared to placebo (artificial sweetener), 6 g of essential amino acids plus 35 g of sucrose promoted a transient net increase in muscle protein balance during the hour immediately following beverage ingestion. Based on earlier work, these authors postulated that CHO added to amino acids would produce an interactive effect such that the net response would be greater than the sum of the individual responses; however, the precise role of insulin in the regulation of muscle protein

turnover remains unclear (see Wolfe, 2002). Indeed, Børsheim et al. (2002) found that ingesting 6 g of essential amino acids (without CHO) during recovery produced a transient net increase in muscle protein balance that was comparable to that observed by Rasmussen et al. (2000). The overall magnitudes of the increases in muscle protein balance reported by Børsheim et al. (2002) and Rasmussen et al. (2000) were even higher than the values reported by Tipton et al. (1999), who provided 40 g of essential amino acids. However, direct comparisons between studies are hampered by the fact that Børsheim et al. (2002) and Rasmussen et al. (2000) calculated muscle protein net balance in hourly blocks following beverage ingestion, whereas the earlier study by Tipton et al. (1999) averaged the muscle response over a 4-h period and thus probably underestimated the acute increase that occurred immediately following beverage ingestion.

Tipton et al. (2001) proposed that consumption of an amino acid-CHO supplement prior to exercise is even more effective than a post-exercise supplement at stimulating muscle anabolism during recovery. They reported that protein net balance during the first hour of recovery was significantly higher when subjects ingested an amino acid/CHO supplement immediately prior to a bout of heavy resistance leg exercise, as compared to immediately following the bout. The exercise protocol and composition of the supplement provided were identical to that used by Rasmussen et al. (2000). However, a notable discrepancy between studies involved the relative increase in muscle protein synthesis and net protein balance when subjects consumed the supplement during recovery. Tipton et al. (2001) observed a small, non-significant increase in protein net balance from 0-1 h after exercise when subjects consumed the supplement immediately following the bout, whereas Rasmussen et al. (2000) reported a much larger increase during the 1-2 h or 3-4 h post-exercise period when subjects ingested the supplement at 1 h or 3 h following exercise, respectively. The explanation for this discrepancy is not immediately clear, although direct comparisons between studies are hampered by the fact that different methods were used to calculate muscle protein turnover.

The apparently beneficial effects of amino acid/CHO supplements on net protein balance during the first few hours following resistance exercise are intriguing. This acute anabolic response of muscle to exercise and amino acid ingestion seems to persist for at least 24 h (Tipton et al., 2002). However, it remains unclear whether such effects continue over several weeks or months of resistance training and lead to accelerated rates of muscle protein accretion.

### **Post-exercise Protein Ingestion and Adaptations to Chronic Resistance Training.**

Esmarck and coworkers (2001) reported that “early” intake of an oral protein supplement during recovery was essential for the development of skeletal muscle hypertrophy in elderly men in response to chronic heavy resistance training. Subjects in that study ingested a supplement containing 10 g protein, 7 g CHO, and 3 g fat either immediately or 2 h following each workout during a 12-wk (3x/wk) resistance training program. (There was no control group that received no supplement.) Food intake was controlled during the 2 h following each exercise bout, but thereafter subjects were permitted free access to food. The most notable finding from this study was that cross sectional area of the quadriceps femoris (and its fibers) increased only in the group supplemented immediately after their workouts. The

absence of change in the group supplemented 2 h after exercise is surprising given that previous studies have reported increases in muscle and muscle fiber cross-sectional area after comparable training programs in elderly individuals (Frontera et al., 1988; Welle et al., 1996). Although post-exercise dietary habits were not reported in these other investigations, it is unlikely that subjects were specifically instructed to consume food immediately following exercise, and yet all training groups experienced gains in muscle mass. Nonetheless, the investigation by Esmarck et al. (2001) represents the first attempt to specifically investigate the issue of nutrient timing in association with resistance training on muscle fiber hypertrophy.

### **SUMMARY**

Protein and amino acid ingestion can acutely modify the metabolic response of muscle during recovery from strenuous exercise. However, with respect to prolonged aerobic work, it appears that protein or amino acid ingestion does not enhance the rate of muscle glycogen resynthesis, provided that carbohydrate is ingested in sufficient quantities and at an optimal rate. In contrast, a relatively small dose of essential amino acids has clearly been shown to enhance net muscle protein anabolism during the first few hours of recovery from heavy resistance exercise. With respect to the latter finding, two important issues that remain to be resolved are whether the marked, transient increase in muscle protein net balance that occurs in response to acute supplementation results in a significant accretion of muscle protein after many weeks of resistance training, and whether ingestion of specific nutritional formulations is more effective than simply ingesting ‘normal’ food. As evidenced by the recent findings of Esmarck and colleagues (2001), there is a clear need for long term studies designed to elucidate the time course and magnitude of change in muscle protein metabolism over several days, weeks and months of resistance training, in order to properly assess the potential impact of specific nutritional interventions on the rate of muscle fiber hypertrophy.

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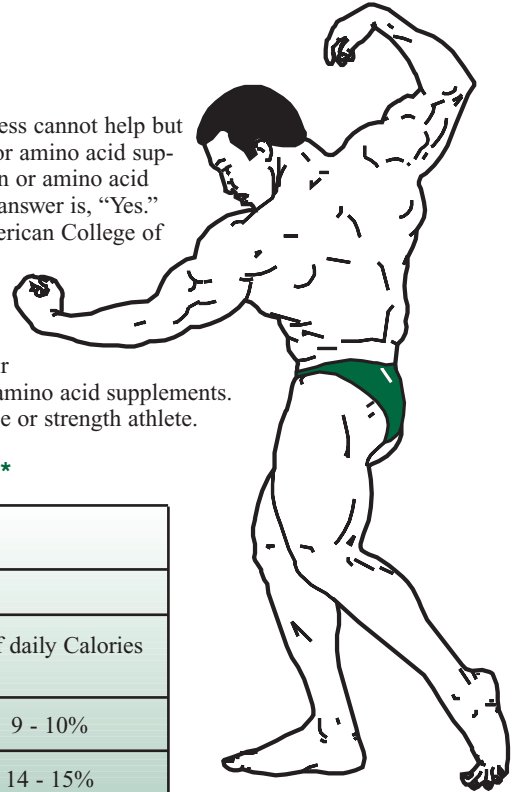
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# PROTEIN AND AMINO ACID SUPPLEMENTS: DO THEY WORK?

## How Much Protein Do Athletes Need?

Any athlete who scans the pages of one of the numerous magazines devoted to strength and fitness cannot help but be intrigued by the numerous advertisements and articles that promote various types of protein or amino acid supplements—powders, bars, drinks, and tablets. Do athletes really need massive amounts of protein or amino acid supplements to maximize their performance? For many body builders and strength athletes, the answer is, “Yes.” But what do the experts on nutrition, exercise, and medicine say? Organizations such as the American College of Sports Medicine (ACSM), American Dietetic Association (ADA), and Dietitians of Canada (DC) have concluded that athletes have only slightly higher protein requirements than do non-athletes. Moreover, the vast majority of athletes consume protein in their normal diets far in excess of any increased protein requirement. Provided that sound nutrition principles are followed and energy intake is sufficient to maintain body weight, athletes require about 15% of their total caloric intake from protein and do not need to fortify their diets with expensive protein or amino acid supplements. Table 1 provides an example of the daily energy and protein requirements for a typical endurance or strength athlete.



**TABLE 1. Protein requirements for active individuals.\***

Type of Athlete	Daily Requirement for a 70 kg (154 lb) Individual <sup>1</sup>			
	Energy (Calories/day)	Protein		
		grams protein per kg [lb] body weight per day	grams/day	% of daily Calories
Endurance <sup>2</sup>	3800	1.2-1.4 [0.55-0.64]	84 - 98	9 - 10%
Strength <sup>3</sup>	3200	1.6-17 [0.73-0.77]	112 - 119	14 - 15%

\*Values are based on ACSM/ADA/DC Joint Position Statement (2000) and assume <sup>1</sup>a resting energy expenditure equivalent to 40 Calories per kilogram (18 Cal/lb) of body weight per day; <sup>2</sup>a male runner who runs 10 miles per day at a pace of 6 minutes per mile with an energy expenditure of running of 0.25 Calories per minute per kilogram of body weight (0.11 Cal/min per lb); and <sup>3</sup>an additional cost of 6 Calories per kilogram body weight (2.7 Cal/lb) per day for heavy resistance training.

## Protein Supplements and Muscle Glycogen Resynthesis After Prolonged Exercise

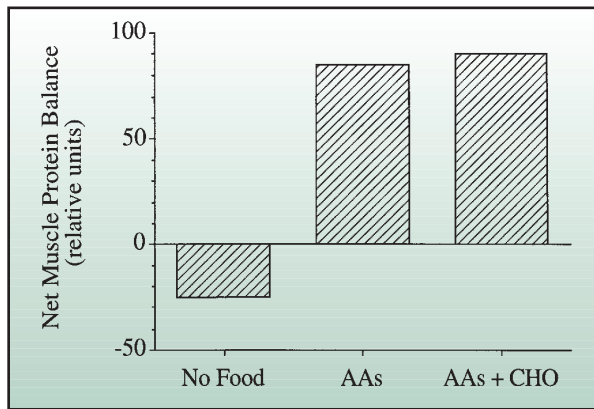
Muscle glycogen is the predominant fuel catabolized for energy during heavy exercise, and the ability to rapidly replenish glycogen stores during recovery is an important concern for athletes, especially those who partake in exercise bouts of long duration or more than once a day. Eating lots of carbohydrate after exercise accelerates muscle glycogen resynthesis during the initial few hours of recovery, and several recent studies suggested that consuming protein along with the carbohydrate might augment this response. Although specific amino acids such as glutamine and possibly arginine may increase post-exercise glycogen resynthesis in some circumstances, particularly in the absence of carbohydrate intake, from a practical standpoint, it appears that protein ingestion does NOT enhance the rate of muscle glycogen resynthesis when carbohydrate is consumed in sufficient quantities. As a general guideline, endurance athletes should consume carbohydrate at a rate of at least 1.2 grams per kilogram of body weight (0.55 g/lb) each hour (in 15-30 minute intervals) during the first 3-5 hours of recovery from prolonged exercise in order to maximize the rate of muscle glycogen resynthesis.

## Muscle Protein Turnover After Resistance Exercise: The Effect of Amino Acid Ingestion.

Heavy resistance exercise (e.g., weightlifting) increases the rates of both protein synthesis and protein breakdown in muscle for some hours after a workout, but in the absence of food intake, the rate of breakdown exceeds the rate of synthesis. This means that if weightlifters do not eat after they work out, they actually begin to lose muscle mass! It appears that only a small amount of food is required to produce an environment within the muscle that favors protein building, at least for a few hours. For example, ingesting a drink containing 6 grams of essential amino acids, either immediately prior to exercise or during the first few hours of recovery, seems to promote an “anabolic” environment within the muscle (Figure S1). Although not yet proven, this may lead to enhanced muscle growth during habitual training.

Athletes who want to try supplementation should consume about 0.1 gram of essential amino acids per kilogram of body weight, either immediately prior to heavy resistance exercise or during the first few hours of recovery from the exercise. Some studies have suggested that ingesting carbohydrate (e.g., 0.5 gram per kilogram of body weight) with amino acids may be even more effective for

muscle growth, but the “optimal” beverage composition remains unclear. This does not mean that athletes need to ingest protein shakes or nutrition bars following exercise, although these are a convenient (if expensive!) method to obtain food energy. It is likely that the energy contained in “regular” food is just as effective, and examples of foods that contain the amounts of essential amino acids (and carbohydrates) listed above include one cup of chocolate skim milk or one cup of non-fat fruit yogurt.



**FIGURE S1.** Likely pattern of change in muscle protein balance following heavy resistance exercise when individuals consume no food or a small dose of essential amino acids (AAs, e.g., 6 g), either alone or in combination with carbohydrate (CHO, e.g., 35 g). Note that food ingestion immediately prior to exercise or during the first few hours of recovery promotes a transient increase in net muscle protein balance (i.e., an ‘anabolic’ environment which is positive for muscle growth).

## SUGGESTED ADDITIONAL RESOURCES

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