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AMINO ACIDS, PROTEINS, AND EXERCISE PERFORMANCE

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KEY POINTS

- In all but a few exceptional cases, the maximal contribution of protein as an energy source during exercise ranges between 2% and 10% of the total energy expended.
- In theory, amino acids could contribute to carbohydrate metabolism during exercise, but there is no hard evidence that this occurs or has any bearing on sport performance.
- Supplementation of the athlete's diet with branched-chain amino acids apparently does not benefit exercise performance.
- The most important factors for optimizing muscle growth when one trains with resistance exercise are making certain that the resistance is adequate, that the intake of dietary energy (calories) is sufficient, that at least a small amount of carbohydrate and/or protein is consumed immediately after each training session, and that the athlete obtains plenty of rest between training sessions.
- With rare exceptions, the maximal daily dietary protein requirements for athletes are in the range of 1.2-1.6 grams of protein per kilogram of body weight or about 3-4 ounces of protein per day for an athlete who weighs 160 pounds. This amount of protein can almost always be obtained in the normal diet.
- There is no solid evidence that special mixtures of amino acids provide any advantage over normal dietary proteins in stimulating muscle growth.

INTRODUCTION

For many years, experts and non-experts alike have been debating the question of whether or not athletes, particularly those who wish to gain muscle mass, should consume extraordinary amounts of protein in their diets. Protein powders and special amino acid mixtures have held their places among the top sellers in the dietary supplement field for as long as most of us can remember. Athletes presumably spend hundreds of millions of dollars annually on protein shakes and flakes, but it is impossible to know for certain if these products have made any difference in their physiques or in the performance of their sports.

What contribution does protein make to the energy requirements for weight lifting compared to endurance running or cycling? Does the consumption of carbohydrate speed up the production of protein in muscles? How much protein do athletes in various sports need in their diets? Can this protein intake be achieved by consuming normal foods, or should athletes be ingesting protein supplements? Are proteins good enough, or is it better to consume specific mixtures of amino acids that are purported to markedly improve protein buildup in the muscles? We asked these and other questions to a panel of experts in amino acid and protein metabolism. Each of these respondents has had extensive experience with cutting-edge research in metabolism at rest and during exercise. (Afew of their many scientific publications are cited at the end of this roundtable.) Moreover, each of the panelists has a background of athletic participation and thus appreciates the practical aspects of this topic.

1. How much of the energy expended during exercise of various types can be attributed to the use of proteins and amino acids as fuels?

Gibala: The majority of energy for all types of exercise is derived from carbohydrates and lipids. For short-duration exercise (e.g., sprinting or weightlifting), the contribution of amino acids and proteins to energy production is negligible, regardless of intensity. During more prolonged forms of exercise (e.g., endurance cycling or distance running), recent studies suggest that the oxidation of amino acids accounts for approximately 2-5% of the total energy expenditure. There are conditions during which the energy contribution from amino acids may be higher, e.g., when initial muscle glycogen stores are low, but the maximal energy contribution from protein sources during prolonged exercise is probably less that 10%.

Tipton: It seems to be dependent on the type and intensity of exercise. For endurance exercise, the estimates vary from 2-3% up to maybe as much as 10%. I'm not familiar with any estimates for resistance exercise.

Hargreaves: It is generally accepted that the contribution of proteins and amino acids to energy metabolism during exercise is relatively small. Depending upon the exercise intensity and duration, in addition to the nutritional status of the individual, this contribution varies between 3% and 10% of total energy expenditure.

2. Even if proteins contribute relatively little energy by themselves, does the breakdown of proteins to amino acids accelerate the production of energy from carbohydrates during exercise?

Hargreaves: Amino acids can participate in reactions that generate molecules involved in the metabolic processes that lead to oxidation of carbohydrates, and these reactions speed up during exercise. However, we still do not know if this potential involvement of amino acids has any bearing on exercise performance.

Gibala: The metabolism of amino acids certainly influences other metabolic processes, but, as Dr. Hargreaves has suggested, the significance of these interactions during exercise remains debatable. A notable example of this interaction occurs at the level of the tricarboxylic acid (TCA) cycle, which is a series of metabolic reactions that form a critical pathway involved in carbohydrate (and fat) oxidation. Several metabolic "intermediates" in the TCAcycle take part in side reactions involving amino acids; thus, the metabolism of amino acids can potentially affect the oxidation of carbohydrate. For example, the amino acid glutamate can be a key contributor to the rapid increase in TCAcycle intermediates that occurs at the onset of exercise, whereas the oxidation of leucine, another amino acid, may reduce the concentrations of TCAcycle intermediates during prolonged exercise. It has been suggested that these changes influence the capacity for aerobic energy production, but recent studies have indicated that changes in TCAcycle intermediates during exercise are unrelated to TCAcycle function. Thus, in the case of the TCAcycle, a theoretical argument can be made that amino acids influence carbohydrate oxidation during exercise, but there is no strong evidence to support this argument.

Tipton: There is evidence indicating that some of the amino acids make an important contribution by providing TCAcycle intermediates, without which aerobic metabolism may be limited. Still, the evidence on this score is incomplete, and I would not recommend ingesting amino acid supplements or proteins in the hope that they would noticeably accelerate carbohydrate metabolism.

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3. What are the basic determinants of whether or not muscle size increases when one trains with resistance exercise?

Tipton: The primary stimuli for determining muscle growth are the resistance exercise training and the interaction of the training with food intake. There seems to be a certain threshold of intensity of exercise, below which no significant increases in muscle size will occur, perhaps due to a lack of stimulation of net muscle protein synthesis. Additionally, it seems that exercise that is too intense may inhibit protein synthesis, thus reducing the potential for muscle growth. It is also likely that insufficient rest will inhibit muscle growth during a training period. Although it is not yet clear exactly what diet composition best stimulates muscle growth, it is certain that muscle growth will be limited if insufficient calories are consumed. It is likely that minimum amounts of protein and carbohydrates are necessary as well, but what these levels are has yet to be determined. Of course, the overall effect is constrained by one's genetic limits.

Gibala: There are many factors that ultimately determine the response of skeletal muscle to resistance exercise, but the essential determinants are: (1) the intensity of the loading, e.g., the weight lifted, (2) the nutritional state of the individual, particularly immediately after the exercise period, and (3) the duration of recovery between successive workouts. Application of the overload principle suggests that a training load of at least 60-70% of the one-repetition-maximum (1RM) is the minimal load required to stimulate muscle fiber hypertrophy. For most individuals, the optimal intensity (which corresponds to about 80% of 1RM for most exercises) is a load that can be lifted 8-12 times before failure. Post-exercise feeding is also very important. Ingestion of protein and/or carbohydrate during the 1-2 h period immediately following a bout of resistance exercise potentiates the effect of exercise alone in stimulating the buildup of muscle protein. Notably, a relatively small amount of food, e.g., the energy contained in 1/2 cup of yogurt or a typical sports energy bar, may invoke such a response. However, the research completed thus far has studied metabolism and the effect of protein feedings for only a few hours. There is a clear need for long-term studies designed to clarify the time course and the magnitude of changes in muscle protein metabolism and the impact of nutritional interventions on the rate of fiber hypertrophy over days, weeks, and months of resistance training and feedings. Finally, adequate recovery between training sessions is crucial because the tissue damage caused by resistance exercise may persist for 3-5 d in experienced weightlifters and much longer in persons who are just beginning a training program. As a general rule, it is wise to avoid working a muscle if there is residual soreness from a preceding day's workout.

Hargreaves: I concur with my two colleagues that the most important factors for optimizing muscle hypertrophy are choosing an adequate resistance load and consuming enough dietary energy. Protein and carbohydrate consumption are secondary to these two considerations.

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4. How much dietary protein should an endurance athlete or a strength athlete consume on a daily basis? Can this protein intake be achieved on a normal diet, or are special protein supplements required?

Hargreaves: Strength and endurance athletes may need to consume 1.2-1.6 grams of protein per kilogram body weight each day (about 3-4 oz. per day for a 160 lb athlete), which is somewhat greater than the Recommended Dietary Allowance. On the other hand, there is some evidence that well-trained endurance athletes may actually use less protein for energy during exercise than do untrained individuals, which would have important implications for their dietary protein requirements. Still, because athletes typically increase their energy intakes during training, they should be able to obtain the protein they need from their ordinary foods and need not resort to special protein supplements.

Tipton: With the possible exception of athletes who are vegetarians, it is extremely unlikely that any athletes in Western countries would need to use protein supplements. There does not seem to be any evidence that a protein intake higher than what most athletes already consume is necessary, as long as energy intake is not too low. However, it is not clear exactly what the protein intake should be on a daily basis. Some studies suggest that protein intake should be higher than the Recommended Dietary Allowance of 0.8 grams of protein per kilogram body weight per day for both endurance and strength athletes. On the other hand, studies from our laboratory indicate that exercise may actually reduce the requirement for protein intake due to the stimulation of muscle anabolism by the exercise itself. This may explain how some endurance athletes, such as the Kenyan distance runners, can thrive on very low protein intakes. Athletes for whom muscle hypertrophy is important are not likely to be able to compete on intakes as low as some of the endurance athletes. I don't think there is a definitive recommendation that can be made with the information we currently possess.

Gibala: Even under the most extreme conditions, maximal daily protein requirements are unlikely to exceed 1.6 grams of protein per kilogram of body weight, and the vast majority of athletes consume ample protein to cover any elevated need. Studies have shown that on average, male and female endurance athletes obtain about 14% of their daily energy from protein, and the relative proportion for male strength athletes is 18%. For example, an active 70 kg individual with a daily energy intake of 3,500 kcal would typically consume at least 120 grams of protein every day. Here is how that calculation is made:

1. Daily energy intake x fraction of that energy consisting of protein = protein calories per day

   Example: 3,500 kcal/d x 0.14 = 490 kcal of protein per day

2. Kcal of protein per day ÷ 4 kcal/gram = grams of protein consumed per day

   Example: 490 kcal /4 = 122.5 grams of protein consumed per day

Assuming that this athlete is engaged in extremely intense training and has a daily protein requirement equivalent to double the RDA (70 kg x 1.6 g/kg = 112 g/day), this requirement is still met by the habitual daily intake. The only athletes who may be at risk for insufficient protein intake in their normal diets are those who consume too little energy (e.g., amenorrheic female runners; wrestlers, gymnasts, and other athletes who compete in weight-certification sports). For the vast majority of athletes, there is no strong evidence calling for protein supplementation.

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5. Is it better to consume special mixtures of amino acids to increase muscle growth, or can proteins in ordinary meals do the job just as well?

Gibala: This question has not been directly examined using the most sensitive analytical methods, but I believe that the proteins in ordinary meals are probably just as effective as amino acid supplements for increasing muscle growth. In a series of studies from one laboratory, it was recently shown that skeletal muscle protein net balance following resistance exercise was increased to a similar extent whether subjects consumed mixed amino acids, essential amino acids, or a combination of amino acids and carbohydrate. It appears that the timing of protein ingestion after exercise, rather than the specific mixture of amino acids or the type of protein ingested, may be the more important factor influencing muscle growth. In addition, frequent feeding of small meals may be preferable to a single large meal in order to help maintain blood amino acid concentrations over a longer period of time.

Tipton: I agree; there is no evidence that consuming special mixtures of amino acids or certain kinds of proteins offers any advantage as far as increasing muscle growth. For most healthy exercisers, including athletes, it is likely that proteins in normal meals will be sufficient to stimulate muscle growth, provided, of course, that the training stimulus is sufficient. There may be a place for special supplements for certain populations, e.g., burn patients, the elderly, and bed-ridden individuals, for whom muscle loss is a problem.

Hargreaves: The amino acids contained in ordinary foods are sufficient; there is no need for supplementation with mixtures of specific amino acids.

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6. How important is it to eat plenty of carbohydrates, in addition to proteins, if one wishes to maximize muscular development?

Gibala: First, to maximize muscular gains, an athlete should be taking in more food energy than is being expended, and carbohydrate should be the major energy source, i.e., at least 50% of total caloric intake. It is notable that although resistance exercise *per se* improves skeletal muscle net protein balance, protein breakdown exceeds synthesis if athletes train while fasted. Second, the rate of glycogen breakdown is very high during resistance exercise, and multiple sets of a single exercise can decrease muscle glycogen content by 20-40%. Therefore, carbohydrate ingestion is especially important following exercise in order to restore muscle glycogen concentrations. Failure to do so may compromise performance during repeated bouts of resistance exercise, especially during periods of heavy volume training for a particular muscle group.

Hargreaves: After eating carbohydrate foods, the carbohydrates are broken down mostly to glucose in the small intestine. As glucose is absorbed into the bloodstream, insulin is released into the blood. Insulin, in the presence of the increased amino acids that accompany the digestion of proteins, stimulates the synthesis of proteins in the muscles. Therefore, my opinion is that it is a good idea to eat meals rich in both carbohydrate and protein to optimize muscle growth.

Tipton: Dr. Hargreaves is probably correct in his assessment, but I prefer a somewhat more cautious approach. We know that for several hours, increased levels of insulin that are associated with carbohydrate digestion decrease protein breakdown and thus tend to increase the amount of protein in the muscles. Additionally, we know that the combination of amino acids and carbohydrates consumed as supplements after exercise will, at least for several hours, cause greater protein synthesis in the muscles. However, it is not clear what influence these acute, transient improvements after ingesting supplements will have on muscle development on a long-term basis, and we don't know if the same effects would occur in response to carbohydrate and protein in ordinary foods consumed at meals on a daily basis. Thus, we do not know for certain how varying amounts of dietary carbohydrate will impact muscle growth in the long run.

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7. Can supplements of branched-chain amino acids (BCAA) taken before and during exercise delay the onset of fatigue?

Hargreaves: If BCAAingestion reduced the uptake of the amino acid tryptophan from the blood into the brain so that less tryptophan were converted to serotonin in the brain and if a buildup of serotonin in the brain caused early fatigue during exercise, a case could be made for consuming BCAAbefore and during exercise. Although there is sound evidence for most, if not all, parts of this scenario, the best studies directly testing the effect of consuming BCAAon performance show that BCAAingestion does not benefit performance. In fact, a potential side effect of BCAAingestion is an increase in plasma and muscle accumulation of ammonia, which itself can contribute to fatigue. On balance, it appears that ingestion of BCAAis not effective in improving exercise performance.

Gibala: The short answer is, No. Despite claims to the contrary, BCAAdo not seem to be important fuel sources during exercise, regardless of intensity, and there is no solid rationale for BCAA supplementation. It is notable that even during very prolonged exercise, the concentrations of BCAAin skeletal muscle do not change significantly, suggesting that there is no shortage of these substrates for energy production. Moreover, carbohydrate loading or carbohydrate ingestion during exercise, as typically practiced by endurance athletes, reduces the contribution of BCAAto probably less than 1% of total energy expenditure. The most well-controlled scientific studies conducted to date have reported no effect of BCAAsupplementation on exercise performance in humans.

Tipton: I think the responses of Dr. Hargreaves and Dr. Gibala are right on target. Some studies published a few years back suggested that BCAAsupplements could delay fatigue during long-duration endurance exercise. However, these studies were not well controlled, and several reports since then have not shown any effect of BCAAsupplements on delaying fatigue under normal circumstances. There is some evidence that these supplements may work in extreme conditions such as high altitude, but, at best, I would say the jury is still out.

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SUPPLEMENT

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HOW MUCH PROTEIN DO YOU NEED, AND WHERE CAN YOU GET IT?

Athletes spend millions of dollars annually on protein powders, protein bars, protein shakes, and numerous types of amino acid supplements, all with the belief that they need tremendous amounts of protein to use as fuel for exercise and to help build proteins in muscles. It is argued by the supplement manufacturers that only "high-quality" proteins can provide optimal muscle growth or that only amino acids are absorbed into the blood quickly enough to maximally stimulate protein buildup in muscles.

As is often the case in the dietary supplements industry, there is an ounce of truth—and a ton of nonsense—in these claims. Here are some facts about protein needs and protein supplements.

- Almost all the fuels used to provide energy for sports are carbohydrates and fats; proteins usually contribute only about 2% of the energy needed, and the maximal contribution of protein to energy in sport is likely to be less than 10%.

- It is true that athletes often need more protein in their diets than do inactive people. Except for a few athletes, the amount needed each day—1.2-1.6 grams of protein per kilogram of body weight (3-4 ounces of protein for a 160-pound athlete)—is still very small. Moreover, this amount of protein can almost always be obtained from ordinary foods in the athlete's normal diet, without resorting to expensive protein supplements.

- There are a few athletes, especially wrestlers, gymnasts, dancers, and others trying to lose weight or avoid weight gain, who may need to eat more protein to compensate for increased protein burning for energy. Still, the maximal amount of protein required for such athletes probably does not exceed 2.5 grams of protein per kilogram of body weight every day.

- It is true that the proteins in some foods, e.g., eggs, milk, and meat, provide a more complete mix of necessary amino acids than do the proteins in other foods such as those found in peas, corn, or wheat. The amino-acid quality scores for these proteins are sometimes stated as the "biological value," the "chemical score," the "net protein utilization score," or the "protein efficiency ratio." So, if all of the dietary protein for an athlete were to come from a single food source, it would be better to eat only eggs or milk or meat. However, this reliance on a single food source for protein would result in many other nutritional deficiencies. As long as an athlete chooses a variety of foods—even if they are all from plant sources, there will be sufficient amounts of the required amino acids in the diet, and the quality of any given protein is of little consequence. Therefore, athletes who spend great sums of money on supplements of whey protein, for example, are unwise; they can get just as much amino acid incorporation into the proteins of their muscles by eating a variety of normal foods, none of which must necessarily include proteins of high quality.

- If you wish to gain muscle mass, you must consume extra food energy, in addition to enough protein. For example, if you want to gain one pound of muscle per week, you should consume an additional 500 kcal of food each day. Otherwise, you will not achieve your goals, no matter how great a proportion of your food is protein.

So, how can you choose ordinary foods that are high in protein? You can check the nutrition labels on the foods you are considering to get a good idea of how much protein will be contained in each serving. For example, a 6 oz. can of tuna packed in spring water contains about 2.5 servings of tuna when drained of water. Each serving contains about 13 grams of protein, so by eating the entire can of tuna, an athlete could consume 13 x 2.5 = 32.5 grams of protein, nearly half the daily requirement for a high-school wrestler in the lower body weight classes. Similarly, 1/2 cup of canned black beans contains about 7 grams of protein, the same amount contained in 2 tablespoons of peanut butter.

Another way to help choose protein-rich foods is to study tables of food composition such as that included in this article. Other tables can be found in libraries, nutrition textbooks, cookbooks, and on the Internet. The U.S. Department of Agriculture (www.usda.gov) publishes on the Internet the *USDANutrient Database for Standard Reference,* perhaps the most complete such reference in existence. The particular table shown in this article is far from complete, but to make comparisons easier, the protein contents are listed per ounce of each food item. Some of the more protein-rich foods are highlighted in boldface, but don't ignore foods with less protein. Each of these foods can contribute to an overall nutritious diet. One drawback of this type of table is that no consideration is given to the volume of the food item that must be eaten to be equivalent to a weight of 1 oz. For example, the volume of an ounce of milk is very small compared to the volume of an ounce of puffed wheat cereal without milk.

In summary, most athletes can obtain all the protein that they need for optimal sport performance and muscular development from ordinary foods contained in their normal diets. There is no need to spend lots of money on protein supplements or amino acid supplements. As long as you consume enough calories and eat a wide variety of foods, the amino acid composition or quality of the proteins in the individual food items is of little or no consequence.

(See Over)

Protein Content of Common Food Items	
Food Item	**Protein Content (grams of protein/ounce of food)**
Breads	1.55-3.42
Cheesecake	1.50
Vanilla Milkshake	0.98
Plain Pancakes	2.10
Cereals (without milk)	
Cheerios	**4.24**
Corn Flakes	2.30
Froot Loops	1.70
Fruit & Fiber	2.99
Life	**5.22**
Oatmeal	0.73
Puffed Wheat	**4.25**
Rice Krispies	1.86
Raisin Bran	2.7-3.1
Special K	**5.58**
Total	2.84
Hard Cheeses	**4.5-8.4**
Cottage Cheeses	3.5-4.9
Most Varieties of Fish	**5.0-7.5**
Shrimp, Boiled	**5.93**
Tuna packed in water	**8.38**
Ground Beef, Lean	**7.0**
Roast Beef, Lean	**8.1-9.0**
Beef Frankfurter	3.20
Cooked Chicken/Turkey	**7.7-9.3**
Turkey Frankfurter	**4.05**
Turkey Ham	**5.37**
Cooked Eggs	2.9-3.5
Milk	0.93-0.97
Yogurt	1.2-1.6
Vegetables	
Green Beans, Cooked	0.4-0.5
Navy Beans, Cooked	2.46
Corn, Cooked	0.80
Lentils, Cooked	2.56
Peas, Cooked	1.5
Potatoes, Cooked	0.5-1.1
Spinach, Cooked	0.84
Tofu (soybean curd)	2.29
Almonds, Dried or Toasted	**5.7**
Spaghetti, Cooked	1.0-1.4
Pizza with Cheese	3.54
Pizza with Cheese and Pepperoni	**5.94**

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