Protein for Sports–New Data and New Recommendations

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SUMMARY

ESTIMATION OF OPTIMAL PROTEIN AND/OR AMINO ACID INTAKE FOR PHYSICALLY ACTIVE INDIVIDUALS HAS BEEN HISTORICALLY PROBLEMATIC BECAUSE (A) SUBJECTS CONSUMING THE SAME ABSOLUTE AMOUNT OF PROTEIN COULD CONSUME DIFFERENT AMOUNTS AND TYPES OF AMINO ACIDS, (B) THE TIMING OF INGESTION (PRE VERSUS POST EXERCISE) ALTERS PROTEIN KINETICS (SYNTHESIS VERSUS BREAKDOWN), AND (C) THE ADDITION OF NONPROTEIN ENERGY (CARBOHYDRATE) AFFECTS PROTEIN KINETICS.

INTRODUCTION

In the past, exercise scientists and coaches have often debated the amount of protein that athletes should eat to optimize gains in strength and lean mass. Recently, it has become clear that quality (i.e., the type of protein) and timing (i.e., when an athlete eats relative to the exercise stimulus) trump overall protein intake, particularly in athletes who already consume adequate energy and protein in excess of the recommended dietary allowance (RDA). In this regard, although many researchers and authors have made suggestions regarding protein intake (which typically range from 1.2 to 2.0 g/kg body mass per day), this brief review will attempt to synthesize newer data and make specific recommendations regarding periworkout supplementation with essential amino acids/protein and carbohydrates.

Several recent peer-reviewed studies have investigated the influence of nutrition and resistance exercise on muscle protein accretion and, to a lesser extent, cellular signaling in human skeletal muscle. Net protein balance is quite obviously the arithmetic difference between muscle protein synthesis (MPS) and muscle protein breakdown (MPB). Research to date indicates that the magnitude of change in MPS is 10- to 20-fold greater than MPB; therefore, strategies that increase serum amino acid levels (particularly the essential amino acids) should maximize the anabolic response to resistance training. In this regard, a food protein has generally been considered "complete" if it contains all 9 essential amino acids and is theoretically better suited for tissue growth and repair (Table).

However, the phenomenon of MPS has recently been subjected to both an increased scientific scrutiny and a more refined precision of investigative techniques. For example, because MPS is not simply regulated by an unadorned "on/off" switch, studies have selectively examined the importance of influential and indicative factors such as protein turnover, nitrogen balance, essential amino acid ingestion, choice of protein (e.g., milk versus soy), and most recently, the cellular and molecular mechanisms regulating protein turnover, for excellent reviews, see references (3,10,12). This latter aspect of muscle physiology may be somewhat novel to many readers; therefore, a simplified schematic highlighting what are thought to be the most important MPS molecular pathway intermediates is included (Figure). It should be noted that other signaling pathways very likely contribute to the overall adaptive (anabolic) responses in muscle, but their discussion is beyond the scope of this article.

MILK BEATS SOY AS A POSTEXERCISE ANABOLIC AGENT

Eight young men who regularly engaged in resistance exercise (i.e., trained at least 4 days per week) were studied in a crossover design using unilateral resistance exercise (5). After a standardized breakfast, arterial and venous blood and muscle biopsy samples were obtained, and subjects completed a standardized bout of resistance training (4 sets × 10 repetitions at 80% of maximum on the leg press, leg curl, and leg extension, interspersed with 2-minute rest periods). Immediately thereafter, a second series of blood and muscle samples were obtained. Subjects then ingested 500 mL of nonfat milk or an isonitrogenous, isoenergetic, macronutrient-matched soy beverage providing 745 kJ

KEY WORDS:
sports nutrition; protein; amino acids; nutrient timing; lean mass

Table
Amino acids

Essential amino acids	Nonessential amino acids
Histidine	Alanine
Isoleucine*	Arginine†
Leucine*	Asparagine
Lysine	Aspartic acid
Methionine	Cysteine†
Phenylalanine	Glutamic acid
Threonine	Glutamine†
Tryptophan	Glycine†
Valine*	Proline†
	Serine
	Tyrosine†

*Branched-chain amino acid.

†Conditionally essential amino acid.

(178 kcal), 23 g carbohydrate, 18 g protein, and 1.5 g fat. After drink consumption, serial samples of arterial and venous blood, along with muscle biopsies were obtained every hour thereafter for 3 hours. These measurements, along with pulsed Doppler ultrasonography and primed constant infusion metabolic tracers, allowed the calculation of amino acid uptake across the exercised leg and muscle fractional (protein) synthetic rates. Results indicated that although both soy and nonfat milk both increased net protein balance, the increase from nonfat milk was significantly greater. Specifically, MPS rates were 34% higher after consumption of nonfat milk. Interestingly, because the essential amino acid content of the 2 drinks was similar (i.e., approximately 7.5 g), the researchers proposed that soy protein, because of its more rapid rate of digestion, led to a preferential synthesis of serum proteins and urea rather than muscle protein.

KEY POINT

Milk protein promotes greater gains in muscle accretion compared with soy protein when ingested immediately after resistance exercise (5).

TEN GRAM OF WHEY PROTEIN STIMULATES MUSCLE PROTEIN SYNTHESIS

Eight healthy resistance-trained men (i.e., approximately 6 years of weight training experience) performed 2 trials in random order to determine the effect of postexercise consumption of carbohydrate (21 g fructose + 10 g maltodextrin) versus carbohydrate plus protein (21 g fructose + 10 g whey protein isolate [containing 4.2 g essential amino acids]) on MPS (9). After an overnight fast, subjects completed 4 sets of 8–10 repetitions at 80% of maximum for the leg press and leg extension exercise. Arterial and venous blood samples, muscle biopsies, and pulsed tracer injections were used to calculate rates of mixed MPS at rest and after exercise. Not surprisingly, insulin levels peaked 30 minutes after ingestion during both trials, and amino acid concentrations peaked 60 minutes after ingestion during the carbohydrate plus protein trial. During the carbohydrate plus protein trial, mixed MPS tended to be higher at rest ($p < 0.06$) and was significantly higher during the postexercise period compared with that during the carbohydrate trial. The authors concluded that a minimal dose of whey protein (10 g), when combined with 21 g of fructose, is sufficient to induce a 2-fold rise in MPS in young men. However, they did acknowledge that their protein dose (which contained only 4.2 g of essential amino acids) may have been suboptimal because other researchers have noted that at least 10 g (and as high as 20 g) of essential amino acids are necessary to maximally stimulate MPS.

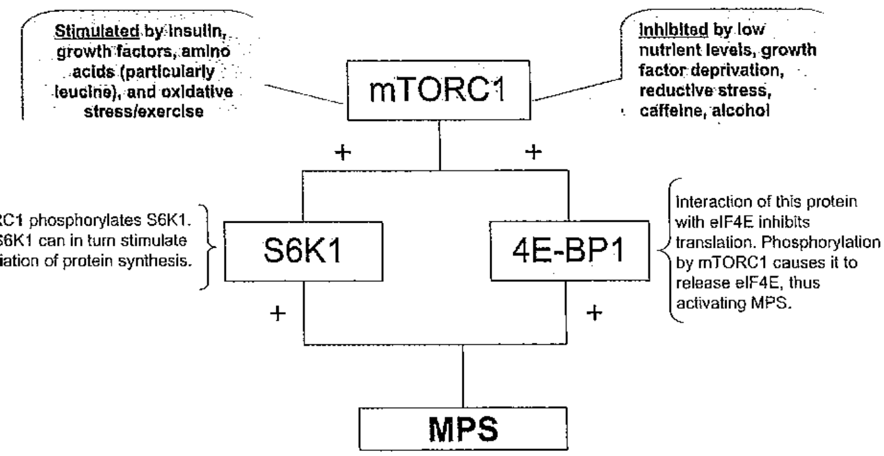

Figure. Simplified schematic of major molecular factors involved in the regulation of skeletal muscle protein synthesis. mTORC1: a complex composed of mTOR (mammalian target of rapamycin), regulatory associated protein of mTOR (aka Raptor), mammalian LST8/G-protein β-subunit–like protein (mLST8/GβL), and the recently identified partner PRAS40. S6K1 = p70-S6 kinase 1. 4E-BP1 = eukaryotic initiation factor 4E (eIF4E) binding protein.

KEY POINT

Although not an optimal dose, 10 g of whey protein (about half scoop of most commercial protein powders) is sufficient to increase MPS in young men (9).

DOSE-RESPONSE EGG PROTEIN STUDY

It has been well established that the anabolic effects of resistance exercise are enhanced when protein or essential amino acids and/or carbohydrate are provided in the periworkout period. Using each subject as their own control, researchers recently examined the dose-response effects of whole egg protein in 6 young fasted men who completed an acute bout of resistance training (i.e., 4 sets × 8–10 repetitions each of leg press, leg extension, and leg curl) and then ingested 0, 5, 10, 20, or 40 g of whole egg protein (8). Using a primed constant infusion of 13C-leucine, venous and arterial blood samples, and repeated muscle biopsies, measurements of mixed muscle fractional synthesis rates were found to increase in a dose-dependent manner up to 20 g, where values reached a plateau at approximately 93% above the baseline (i.e., fasted) condition. At the 40-g dose, no further increase in mixed MPS was noted, and instead a significant stimulation of whole body, leucine oxidation occurred. This study showed that amino acid availability in the postexercise period is the key factor in driving muscle growth and that 20 g of whole egg protein, which is equivalent to approximately 8.6 g of essential amino acids, is sufficient to maximally stimulate mixed MPS after lower-body resistance exercise. It is important to note that no carbohydrates were given in this study, and the benefit of carbohydrate ingestion on protein kinetics is a decrease in MPB (which then magnifies the increase in net protein balance).

KEY POINT

If only protein is consumed in the postexercise period (which is not recommended, see Practical Applications), a 20-g dose of egg protein will maximize MPS (8).

AGING DELAYS MUSCLE PROTEIN KINETIC RESPONSES

After the age of 30, muscle loss occurs at a rate of at least 5% per decade. Although resistance training is an effective stimulus for lean mass accretion and helps attenuate age-related muscle loss, its effect on stimulating muscle growth is blunted in older versus younger adults. Similarly, low doses of essential amino acids result in lower net MPS in older versus younger men. A recent study compared the effects of high-dose essential amino acids (20 g) on anabolic signaling proteins in 7 young (average age = 29.7 years) versus 6 old (average age = 70.0 years) men (4). Subjects completed 8 sets × 10 repetitions of leg extension exercise interspersed with 3-minute rest periods. Continuous infusion metabolic tracers and repeated biopsies revealed that younger men increased their rates of fractional (mixed) MPS from 1 to 6 hours after exercise, whereas older men only noted a significant increase from 3 to 6 hours after exercise. Researchers speculated that the reduced anabolic signaling effects were because of a lower insulin response (or impaired insulin signaling) in the older men.

KEY POINT

Anabolic signaling in young subjects is quicker and more pronounced than that in old subjects when 20 g of essential amino acids are administered after acute resistance exercise (4).

WHEY ISOLATE BEATS CASEIN FOR STRENGTH AND SIZE GAINS

Whey protein is currently considered to be one of the highest quality proteins available, particularly whey isolate, which is rapidly digested and contains high levels of essential amino acids and almost no lactose (i.e., <1.0%). Casein, which makes up approximately 80% of bovine milk protein, is digested more slowly and contains approximately 10–20% less essential amino acids per gram of protein. A landmark study published in 2006 reported that 13 recreational bodybuilders who supplemented their diet with 1.5 g of whey protein isolate per kilogram of body mass per day gained significantly more lean mass (approximately 4.2 kg) and strength (approximately 23 kg in the squat, 30 kg in the bench press, and 15 kg in the lat pull-down) than subjects ingesting the same amount of casein during a supervised 10-week resistance training program (2). Subjects in the whey isolate group also lost 1.4 kg of body fat, whereas values for subjects in the casein group did not change. It should be noted that the total protein dose was divided into 4 equal servings and consumed throughout the day (i.e., breakfast, lunch, posttraining, and dinner).

KEY POINT

During resistance exercise training, supplementation with whey isolate leads to significantly greater gains in lean mass and strength and significantly greater loses of body fat compared with supplementation with casein (2).

NUTRIENT TIMING ENHANCES ADAPTATIONS TO RESISTANCE TRAINING

In the past, dietary recommendations for athletes targeted daily amounts for the intake of total energy, carbohydrates, proteins, and fats, but little importance was placed on when meals were consumed relative to training. A classic study demonstrating the benefits of periworkout nutrition or "nutrient timing" on muscle fiber hypertrophy, strength, and body composition during training was performed by Cribb and Hayes (1). In a single-blind randomized design, 17 young resistance-trained men were matched for strength and placed into 1 of 2 groups; the PRE-POST (preworkout and postworkout) group consumed 1 gram per kilogram of body mass of a nutrient mixture containing glucose, whey isolate, creatine monohydrate, and a small amount of fat immediately before and after resistance exercise (e.g., an 80-kg participant consumed 34 g glucose, 32 g whey isolate, 5.6 g creatine, and 0.4 g fat.). The morning and evening (MOR-EVE) group consumed the same dose of the same supplement before breakfast and before retiring to bed. After 10 weeks of supervised resistance training, the PRE-POST group demonstrated significantly greater increases in lean body mass, 1 repetition maximum (RM) strength in 2 of 3 exercises (bench press and squat), type II muscle fiber size, and contractile protein content. This study highlights the notion that the timing of "meals" surrounding the workout period has a tremendous impact on adaptive responses to resistance training.

KEY POINT

It is not just what you eat, but when you eat it, that determines the overall success of a resistance training program (1).

PRE- OR POSTINGESTION OF WHEY PROTEIN YIELDS SIMILAR EFFECTS ON MUSCLE PROTEIN BALANCE

Two groups of healthy participants were randomly assigned to ingest 20 g of whey protein immediately before or 1 hour after the performance of 10 sets × 8 repetitions of leg extensions at 80% of 1RM (11). Muscle biopsies from the vastus lateralis were taken to measure intracellular amino acid concentrations, and blood flow was measured using indocyanine green infusion. Before exercise, background blood samples for insulin concentration were taken, and additional arterial blood samples for insulin analysis also were collected periodically throughout the protocol: 120, 150, 180, 240, and 300 minutes after exercise. Arteriovenous samples were taken before and at regular intervals after exercise, up to 300 minutes, to calculate net muscle protein balance. Arterial amino acid concentrations were elevated by approximately 50%, and net amino acid balance switched from negative to positive after ingestion of protein at either time point. Amino acid uptake was not significantly different between conditions when calculated from the beginning of exercise or from the time of ingestion of each whey solution.

KEY POINT

Unlike essential amino acids, ingesting 20 g of whey protein either before or 1 hour after resistance exercise has similar effects on muscle protein balance (11).

WHEY PLUS CASEIN TRUMPS CARBOHYDRATE

Nineteen healthy but previously untrained men were randomly assigned to supplement their diet with either 20 g of protein (14 g of whey and casein protein, 6 g of free amino acids) or 20 g of dextrose 1 hour before and after resistance exercise (14). Both groups completed a 4-d/wk training program that included 2 upper- and 2 lower-body workouts per week. The exercise regimen incorporated the principles of overload and progressive resistance, using 3 sets of 6–8 repetitions at 85–90% of the 1RM. Blood samples (for insulin-like growth factor-1 (IGF-1) and insulin) and vastus lateralis muscle biopsies (for various markers of muscle anabolism) were obtained before and after 10 weeks of training. Results indicated that subjects in the protein/amino acid blend group had significantly greater increases in total body mass, fat-free mass, thigh mass, muscle strength, serum IGF-1, IGF-1 messenger RNA (mRNA), major histocompatibility complex I and IIa expression, and myofibrillar protein.

KEY POINT

A 10-week heavy resistance training program combined with the ingestion of a blend of whey and casein protein plus free amino acids is more effective than an isocaloric carbohydrate placebo for improving muscle strength, lean mass, and markers of muscle anabolism (14).

RESISTANCE TRAINING AND PROTEIN INGESTION POSITIVELY AFFECTS GENE EXPRESSION

A recent study investigated the long-term adaptations of adding a high-quality protein to the "normal diet" of healthy males undergoing resistance training (6). Thirty-one male participants were randomized into protein supplementation, placebo, and control groups. Measurements of muscle cross-sectional area (via magnetic resonance imaging) and muscle force production (via dynamometry) were made before and after 21 weeks of heavy resistance training (i.e., more than 40 bouts of lower-body resistance exercise). For examination of acute changes, muscle biopsies were taken from the vastus lateralis before and at 1 hour and 48 hours after 5 × 10 repetitions of leg press exercise. The examination of chronic changes was made via an additional biopsy after 21 weeks of resistance training. Protein supplementation (15 g of whey) or a nonenergetic placebo was provided to the participants both before and after each bout of training. Results demonstrated that subjects in the protein group noted significantly greater increases in vastus lateralis cross-sectional area. Significant increases were also noted in muscle hypertrophy–related gene expression both acutely and chronically. Also, protein intake seemed to prevent the 1-hour post–resistance exercise decrease in myostatin, the satellite cell differentiation regulator myogenin, and mRNA expression but did not affect other myostatin-related factors such as activin receptor IIb, p21, follistatin-related gene (FLRG), muscle atrophy F-box (MAFbx), or MyoD expression.

KEY POINT

Long-term whey protein intake before and after resistance exercise alters anabolic signaling in a manner that is advantageous for muscle hypertrophy (6).

PROTEIN PLUS CARBOHYDRATE AUGMENTS ANABOLIC SIGNALING

The increase in MPS in response to an acute bout of resistance exercise occurs before changes in muscle mRNA become apparent (i.e., post-transcriptionally). Currently, activation of the mTOR/PI3K signaling pathway is considered to be one of the keys in controlling the magnitude of the anabolic response in muscle. Seven healthy, untrained, male participants were randomly assigned to 2 crossover experiments to determine the impact of carbohydrate with or without added protein on markers of anabolic signaling in muscle (7). Before, immediately after, and 1 hour after a single bout of lower-body resistance exercise

(8 sets × 10 repetitions of leg extension), subjects consumed a carbohydrate beverage (0.3 g/kg body mass) either with or without added protein hydrolysate (also 0.3 g/kg body mass). Muscle biopsies were taken from the vastus lateralis before and immediately after exercise and after 1 hour and 4 hours of postexercise recovery to determine the phosphorylation (activation) status of the muscle protein growth markers 4E-BP1, S6K1, and S6. Immediately after resistance exercise, there was significantly more phosphorylation of 4E-BP1 in the carbohydrate plus protein trial. The initial phosphorylation of S6K1 was substantially increased after exercise and remained elevated during recovery with no differences between treatments. However, the second (activating) phosphorylation of S6K1 was significantly higher after exercise only in the carbohydrate plus protein trial. During the recovery period, the S6K1 phosphorylation remained significantly higher in the carbohydrate plus protein trial. The phosphorylation of S6 was significantly higher after exercise and during recovery in the carbohydrate plus protein trial compared with that in the carbohydrate only trial.

KEY POINT

This elegant study demonstrates that the combination of dietary carbohydrate and protein enhances the activation of muscle protein growth markers (S6, S6K1, and 4E-BP1) during the recovery from resistance type exercise (7).

MILK BEATS SOY AND CARBOHYDRATES DURING RESISTANCE TRAINING

A group of 56 healthy, young, novice, male weightlifters were trained 5 days per week for 12 weeks using a split-body resistance exercise program (13). Participants were randomly assigned to consume fat-free milk protein, fat-free soy protein, or a carbohydrate control beverage. The beverages were consumed immediately after exercise and again 1 hour later. Measurements of muscle fiber size, maximal strength, and body composition were undertaken both before and after 12 weeks of training. Although no between-group differences were noted for changes in strength, type II muscle fiber area and lean body mass increased significantly more in the milk group compared with the soy and control groups. Type I muscle fiber area increased after training only for the milk and soy consumers, with the increase in the milk-consuming group being significantly greater than in the control group. There was also a significantly greater decrease in fat mass in the milk group compared with that in the soy and control groups.

KEY POINT

The long-term postexercise consumption of bovine milk (which is approximately 80% casein and 20% whey) promotes greater muscle hypertrophy during the early stages of resistance training in novice weightlifters compared with isoenergetic soy or carbohydrate consumption (13).

PRACTICAL APPLICATIONS

Although it is not possible to make conclusive recommendations regarding protein intake for optimal performance, the following observations and recommendations are made considering the current body of literature:

1. Athletes wishing to enhance lean mass from resistance exercise should never train fasted nor remain fasted in the immediate postexercise period. Assuming total energy needs are being met, training-induced gains in strength and lean mass can be significantly improved when athletes are given proper pre- and postexercise (i.e., periworkout) nutrient combinations.
2. With the exception of recent studies on chocolate, milk, and eggs, the effects of whole foods and drinks on MPS and MPB have not been studied in humans. As a result, it should be acknowledged by nutritionists and conditioning professionals that the common "food first" recommendation, at least in the periworkout period, is based almost entirely on speculation from studies using crystalline essential amino acids and carbohydrates.
3. Because of the technical expertise and cost involved in performing metabolic tracer studies, sample sizes are small (often <10 homogeneous subjects), variances are large, and the generalizability of dose-response findings to many athletes is limited. Moreover, the resistance exercise stimulus in most studies to date has used lower-body exercise only (with serial biopsies of only 1 muscle), and the exercise volume is substantially lower than what many athletes actually do. For these reasons, it is our opinion that the optimal protein and/or amino acid–dosing regimen for elite athletes in the periworkout period is probably higher than that recommended by the primary literature, particularly when greater volumes of exercise and/or whole body training is performed.
4. Essential amino acids ingested before resistance exercise lead to a greater increase in muscle protein accretion than when they are ingested after exercise. In contrast, whole whey proteins ingested before or after resistance exercise lead to similar effects on amino acid uptake, regardless of the timing of ingestion.
5. Although the optimal amount of whey protein and whole food choices that are necessary to maximize muscle protein accretion has not been studied to date, a prudent recommendation at this time for strength/power athletes is to consume a postworkout nutrient mixture that contains approximately 2 parts carbohydrates to 1 part protein, where protein intake constitutes 0.25–0.50 grams per kilogram of body mass. For team sport athletes, a 3:1 ratio is recommended. For endurance athletes, a 4:1 ratio is recommended. A similar macronutrient combination should also be consumed every 1–2 hours thereafter for at least 6 hours after exercise

(i.e., a total of 3–4 postexercise "meals" should be consumed within the 6-hour postexercise window) to maximize adaptive responses in muscle. If caloric intake is a concern, then essential amino acids can be used instead of whole protein, with an intake of 0.15–0.30 grams of essential amino acids per kilogram of body mass. One scoop of high-quality whey protein contains approximately 10–12 g essential amino acids.

6. Of all the essential amino acids, leucine appears to be the most important trigger controlling MPS. Although still somewhat speculative, leucine doses of approximately 3–9 g (0.12 g leucine per kilogram of lean body mass) per meal appear necessary to maximally stimulate MPS during the postexercise period. Because older muscle has been shown to have defects in leucine and insulin signaling, even higher amounts of leucine, as well as additional carbohydrates, may be necessary to maximize muscle protein accretion in older athletes. One scoop of high-quality whey protein contains approximately 2–2.5 g of leucine.
7. Coaches and athletes should be encouraged to speak with qualified sports nutritionists to help identify unique nutritional strategies for optimal performance.

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