4 Nutrition for Strength Power Athletes

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INTRODUCTION

Strength and power are important characteristics in the performance of many sports. This is most apparent in lifting events (i.e., Olympic lifting, powerlifting) and throwing events (i.e., javelin, discus, shot put, and hammer). The ability to generate explosive muscle power is also critical to success in sprints (100 to 200 m) and jumping events, as well as intermittent passages of play in team sports like rugby and American football. Bodybuilders strive to develop and enlarge their musculature for competitive exhibition. Due to the potent nature of resistance exercise in promoting strength gains, hypertrophy, and, in certain circumstances, increases in muscle power, athletes competing in these events will typically include some form of resistance exercise into their overall training program. Sport-specific training varies markedly between the different types of athletes and is generally sequenced so as not to interfere with resistance training. While resistance training plays a supportive role in team sports and

track and field events, it is the major training focus in lifting events and bodybuilding. Given the vast heterogeneity in sport-specific training programs of strength-power athletes and their consequent metabolic implications, this chapter will focus on the major nutritional issues underpinning resistance training. The sports of Olympic lifting, powerlifting, and bodybuilding will also be addressed given the emphasis on resistance exercise in the overall training program for these athletes.

WHAT ARE THE FUNCTIONAL DEMANDS OF TRAINING AND COMPETITION?

Resistance training when performed as a small component of the overall training program or as its major focus is usually a planned and sequenced activity. Components of the program are carefully planned within each session, microcycle, and longer training macrocycle (Burke 2007). The outcomes of resistance training that lead to an increase in muscle size or strength include neural adaptations and positive net muscle protein balance, with the contribution of these factors varying according to the stage of the resistance training program. The primary goal of training in powerlifters and Olympic lifters is to enhance strength and power, respectively. Traditional powerlifting training typically involves high-force, low-velocity exercises with mastery usually touted as requiring a decrease in repetition range and increased volume. Periodization of training in Olympic lifters typically involves a transition from high-volume, high-force, low-velocity movements, characteristic of traditional powerlifting, to more explosive, low-repetition training in preparation for competition. The emphasis on higher velocity "explosive" Olympic lifts results in greater improvements in power and strength over more traditional strength-based lifting, derived mainly from neural rather than hypertrophy adaptations, and is increasingly being included in the training of powerlifters (Slater and Phillips 2011). While gains in muscle mass can occur during any phase of training in a traditional powerlifting program, the initial phase of the macrocycle represents the most favorable time for skeletal muscle gains in Olympic lifters (Slater and Phillips 2011). As hypertrophy represents the primary goal of training in bodybuilders, their training programs are usually of greater volume than those of Olympic and powerlifters, incorporating higher repetition ranges with multiple sets per muscle group and short rest periods between sets.

Competition demands of a number of strength-requiring sports are typically characterized by explosive single efforts, with significant recovery between each effort. Thus, the phosphagen energy systems (adenosine triphosphate and phosphocreatine) supply the main fuel source. However, resistance training involving repetitive lifts requires a high rate of energy supply from both the phosphagen energy systems and glycogenolysis. Possible causes of fatigue during resistance exercise include a decline in intramuscular pH, depletion of phosphagen energy system stores, and impaired energy production from glycogenolysis (Slater and Phillips 2011).

WHAT DO STRENGTH-POWER ATHLETES EAT?

While there are a reasonable number of reports on the dietary intakes of national- and international-level male lifters, throwers, and bodybuilders, the majority of these are

over 20 years old and data on the dietary practices of contemporary athletes and elite performers is lacking. Considering the enthusiasm with which strength athletes appear to embrace new scientific findings, as well as fads, it is unfortunate that data that is more recent does not exist (Burke 2007). In addition, studies on female strength-power athletes are less common reflecting perhaps the lower numbers of females involved in these sports. Nevertheless, available data indicate that during normal training phases, these athletes have high absolute energy intakes. This is unsurprising given the muscularity of these athletes and the association between muscle mass and resting energy expenditure, which when added to their exercising energy expenditure would yield a high daily total. However, when expressed relative to body mass, the energy intakes of strength-power athletes are generally similar to those reported for athletes in other sports (Slater and Phillips 2011). Data from national- and international-level competitors suggest that energy intakes tend to fall short of the current strength athlete guidelines of ~185–210 g kg^{-1} d^{-1} body mass, with intakes of approximately 150–180 g kg^{-1} d^{-1} reported in males and 110–150 g kg^{-1} d^{-1} in females (Faber et al. 1986, 1990). The limited number of dietary intake surveys conducted in elite athletes suggests slightly higher energy intakes of 210–240 g kg^{-1} d^{-1} (Chen et al. 1989; Tarnopolsky et al. 1988), although further work is needed to confirm this in modern world-class strength athletes. Alternatively, it has been suggested that the apparent failure of several groups of strength-power athletes to meet energy intake guidelines may be a reflection of the fact that taller and/or more muscular individuals have lower resting energy requirements relative to body mass (Slater and Phillips 2011). Thus, consideration may need to be given to the lower relative energy requirements of larger athletes when determining the adequacy of energy intakes (Slater and Phillips 2011).

Dietary intake data typically show carbohydrate intakes of 3–5 g kg^{-1} d^{-1} in lifters and throwers (Chen et al. 1989; Faber et al. 1990), while bodybuilders appear to consume carbohydrate intakes equivalent to 4–7 g kg^{-1} d^{-1} independent of sex (Kim et al. 2011; Tarnopolsky et al. 1988). The dietary fat intake of lifters and throwers is generally higher than recommended for healthy individuals, usually accounting for ~40% of total dietary intake (Chen et al. 1989; Faber et al. 1990). In contrast, in bodybuilders the majority of dietary surveys report fat intakes closer to 30% of dietary intake (Tarnopolsky et al. 1988), presumably to account for the slightly higher carbohydrate intakes in this group. As expected, protein intakes in strength-power athletes are high with average intakes exceeding 2 g kg^{-1} d^{-1} (Chen et al. 1989; Tarnopolsky et al. 1988), although individual studies have reported mean intakes as high as 4.3 g kg^{-1} d^{-1} (Kim et al. 2011).

It has become increasingly recognized that simply assessing total daily protein intakes of strength-power athletes will not address if protein intake has been optimized to support gains in muscle mass and strength (Slater and Phillips 2011). Indeed, the per meal dose, protein source, timing of consumption, and daily distribution pattern of protein intake are now recognized as key factors influencing adaptations to resistance training. Unfortunately, few studies have examined these aspects of protein consumption in strength-power athletes, making it difficult to determine compliance with current nutritional guidelines not merely in terms of total protein intake but of important modifiers of adaptive responses via protein doses, timing, source, and pattern of intake. Future studies are required to assess the nutritional

intakes and eating patterns of contemporary, elite athletes, with emphasis on the timing of nutrient intake in relation to training.

WHAT SHOULD STRENGTH-POWER ATHLETES EAT?

Training nutrition has a number of important roles for the elite strength-power athlete: improving work capacity acutely (i.e., enhancing the training stimulus) by fueling individual training sessions, promoting recovery between training sessions not only of the muscle but also of connective tissues, supporting body composition and weight category goals and enhancing metabolic and physiological training adaptations, including skeletal muscle hypertrophy.

Strength-power athletes are notorious for high protein intakes. Indeed, historical references to high protein diets date as far back as ancient Greece and the legendary wrestler, Milo of Kroton. It is now generally accepted in the sports nutrition literature that strength-athletes require, or at least can benefit from, protein intakes above the current recommended daily allowance (RDA) of 0.8 g kg^{-1} d^{-1} for the general population. The RDA, which was determined based on the inherently flawed nitrogen balance method and set at a level to prevent deficiency in 98% of the population, is unlikely to reflect the protein intakes required to optimize all aspects of muscle mass, muscle function, and muscle metabolic processes in resistance-training athletes (Phillips et al. 2007). In support of this thesis, a recent meta-analysis concluded that consuming higher protein (either through protein supplementation or a higher protein diet providing >1.2 g kg^{-1} d^{-1}) during prolonged resistance exercise training resulted in significantly greater gains in fat-free mass (~1.0 kg), muscle fiber cross-sectional area (~50%), and strength (~20% for single repetition maximum in the leg press) compared to training without additional protein in young subjects (Cermak et al. 2012). Importantly, these findings were evident despite the fact that, before the intervention, all groups were consuming protein at a level higher than the RDA (~1.2 g kg^{-1} d^{-1}) indicating that ingesting protein above this level promoted greater adaptations to resistance exercise training. Of note, resistance-trained groups were shown to be even more responsive to higher protein intake than their untrained counterparts were, with protein supplementation/high protein diets resulting in a four-fold larger increase in fat-free mass relative to the lower protein conditions. These findings suggest that in strength-power athletes, high protein intake is important in maximizing anabolic responses to training.

In addition to the factors directly related to promoting maximal adaptations to resistance exercise training, the optimal level of protein intake for strength-power athletes should also maintain optimal function of all protein-requiring processes in the body such as the metabolic pathways in which amino acids act as intermediates, immune function, and the production of plasma proteins (Phillips et al. 2007). While it would be extremely difficult to measure the amount of protein required to optimize the functioning of all of these pathways, when we consider that the nature of exercise is such that there is an upregulation of protein-requiring processes, it appears unlikely that the minimal level of protein required by sedentary individuals would provide for the ideal intake in strength athletes (Phillips et al. 2007).

A number of studies have employed the nitrogen balance method in an attempt to determine protein requirements in strength athletes. Data from these studies indicates that the protein needs of athletes can be as high as twice the RDA (Tarnopolsky et al. 1988). While the nitrogen balance method is the method on which the RDA for protein is based, there are a number of serious technical limitations associated with it such as the implausibly high nitrogen balance typically observed with high protein intakes, and increased economy of nitrogen use with low protein intakes (Phillips et al. 2007). Furthermore, the relevance of being in "nitrogen balance" (i.e., satisfying the minimal requirement) to an elite level athlete who wishes to optimize the adaptive response to training, as well as support the optimal function of all physiological protein-requiring processes in the body, is questionable. Thus, alternative approaches have been used. Utilizing isotopically labeled tracers, it was reported that consumption of a "low" protein diet (0.86 g kg^{-1} d^{-1}) by a group of strength-trained athletes resulted in an accommodated state in which whole body protein synthesis was reduced compared with medium (1.4 g kg^{-1} d^{-1}) and high (2.4 g kg^{-1} d^{-1}) protein diets (Tarnopolsky et al. 1992). No difference in whole body protein synthesis was observed between the medium and high protein diets; however, leucine oxidation was increased on the high protein diet, demonstrating that this protein intake was providing amino acids in excess of the rate at which they could be incorporated into muscle or used for other amino acid requiring processes. It is worth noting that these results do not demonstrate that 1.4 g kg^{-1} d^{-1} was required to saturate the need for dietary protein, but merely that 0.86 g kg^{-1} d^{-1} resulted in an adapted state and was insufficient to promote maximal rates of protein synthesis. The measurement of whole body protein synthesis does not necessarily reflect the rates of protein synthesis within individual tissues such as muscle; thus, it is unclear from this study what body proteins were being made at a submaximal rate at 0.86 g kg^{-1} d^{-1}, but if muscle protein synthesis was negatively affected, then clearly these findings would be of relevance to strength athletes.

The optimal intake of protein for strength athletes is difficult to define; however, general guidelines recommend athletes undertaking strength training to ingest up to 1.6–1.7 g kg^{-1} d^{-1} (Slater and Phillips 2011). There is also evidence that an intense period of resistance training reduces protein turnover and improves net protein retention (Hartman et al. 2006). It has been postulated that these data mean that the minimal dietary protein requirements of experienced strength athletes may be lower than the recommended guideline (Slater and Phillips 2011). On the other hand, others have argued that these data do not necessarily indicate that resistance training lowers protein requirements. It has been suggested that weightlifting provides such a potent anabolic stimulus that it may cause a shift in the hierarchy of amino acid requiring processes toward muscle protein synthesis. This could mean a greater proportion of circulating amino acids are taken up by skeletal muscle in both the fasted and fed states, potentially at the adaptive "expense" of other amino acid requiring processes (Phillips 2006).

While there is ongoing debate within the scientific literature regarding the protein requirements of strength athletes, it appears that this may be unnecessary as the majority of these athletes are habitually consuming intakes high enough to promote full function of the multitude of physiological processes that require dietary

protein (Phillips 2006). The extremely high protein intakes reported in some groups of strength athletes (Kim et al. 2011) has led to the safety of such high intakes to be questioned. While exceeding the upper range for protein intake guidelines likely provides no further benefit, merely promoting increased amino acid catabolism and protein oxidation (Moore et al. 2009), the health risks of high protein intake seem to be minimal for otherwise healthy athletes (Phillips 2012). It is worth noting, however, that the body adapts to relatively high protein loads by increasing the capacity for amino acid catabolism. Thus, it is likely that the habitual consumption of a high protein diet means the athlete is "forced" to continue consuming greater protein intakes so that fed state gains can balance fasted state losses. Indeed, at least anecdotally, elite strength-trained athletes who eat extremely high protein intakes up to qualifying competitions report losing substantial amounts of muscle mass when they subsequently reduce their protein intake. Thus, in these situations, athletes should wean themselves off extremely high intakes in order to avoid such losses. Another potential problem with excessive protein intakes is that they may interfere with the ability of some athletes to achieve optimal intakes of other macronutrients, particularly carbohydrate, without exceeding their energy requirements (Phillips 2012). This is more likely to be a problem in athletes with lower energy intakes, such as females, and those involved in sprinting, throwing events, or team sports as training likely poses a greater challenge to glycogen stores than strength athletes who solely perform resistance exercise. Therefore, in these athletes a "more is better" approach to dietary protein may hinder other dietary goals within the wider sports nutrition strategy, potentially resulting in impaired training adaptations and/or limiting the ability to train effectively.

When it comes to the role of dietary protein in supporting optimum training adaptations in athletes, the total protein content of their diet may not be the most important factor to consider. A rapidly growing body of evidence shows that the quantity per meal, source (plant vs. animal), and timing of an athlete's protein intake in relation to the training stimulus, as well as the distribution of protein throughout the day have critically important influences on the overall anabolic response, such that hypertrophy may be quite different despite identical total protein intakes.

TIMING AND THE RATIONALE FOR PROTEIN CONSUMPTION AROUND RESISTANCE TRAINING

Changes in muscle mass result from changes in net muscle protein balance (i.e., the rate of muscle protein synthesis minus the rate of breakdown), with the magnitude and duration of the positive periods of net muscle protein balance determining the extent of muscle hypertrophy (Phillips et al. 2007). A session of resistance exercise stimulates increased rates of both muscle protein synthesis (MPS) and muscle protein breakdown (MPB) for up to 48 h (Phillips et al. 1997). Although resistance exercise stimulates MPS to a greater extent than MPB, the net muscle protein balance only becomes positive when amino acids are ingested (Churchward-Venne et al. 2012). This is primarily accomplished through the synergistic effect of amino acid intake and resistance exercise on MPS and forms the rationale for the recommendation to consume protein in close temporal proximity to the performance of resistance exercise.

When is the optimal time to consume protein with respect to training bouts? Some studies have shown that pre-exercise consumption of protein can enhance MPS, while others have shown no effect (Phillips and Van Loon 2011). Thus, it is currently unclear whether pre-exercise protein feeding can increase MPS and long-term gains in muscle mass. It has been hypothesized that the pre-exercise consumption of a large dose (>20 g) of a leucine-rich, slowly digested, high quality protein might support a robust MPS response if it allows the resultant increase in aminoacidemia to coincide with the post-exercise period (Burke et al. 2012). While this could benefit athletes who struggle to consume adequate protein after a resistance session due to issues related to poor appetite or access to food, further work is needed to determine the efficacy of this potential strategy. Consumption of protein during exercise may accelerate MPS rates and possibly suppress muscle protein breakdown either during the rest intervals between sets or after the exercise bout, potentially contributing to an enhanced anabolic response. However, few studies have examined peri-workout protein ingestion with resistance exercise with the exception of a study from Beelen et al. (2008), who showed that the co-ingestion of protein (0.15 g kg^{-1} h^{-1}) and carbohydrate (0.15 g kg^{-1} h^{-1}) did enhance MPS during a 2-h resistance training session and early into recovery, but this did not extend into the overnight fasting period. However, in an 8-week resistance training study, ingesting whey protein immediately before the start of exercise (0.15 g kg^{-1}) and after each training set (0.006 g kg^{-1}) had no greater effect on muscle mass or strength than did a placebo in previously untrained men (Weisgarber et al. 2012). While it is possible that the relatively small amount of protein consumed after each set (~0.5 g) was too low to produce significant muscle hypertrophy, further work needs to be conducted, especially in well-trained populations, to examine whether there may be any anabolic advantage to consuming protein during exercise for elite strength athletes.

It is unequivocal that immediate post-exercise amino acid provision is an effective nutrition-based strategy to enhance MPS above rates observed with exercise alone (Churchward-Venne et al. 2012). Sport nutrition guidelines emphasize the importance of early post-exercise protein consumption as it has been suggested that a window of anabolic opportunity exists in the early post-exercise period during which protein must be consumed in order for a synergistic effect with exercise to occur. This relates to the fact that exercise-induced increases in rates of MPS are greatest immediately after exercise (~100% to 150% above basal rates), and thus the synergistic effects of exercise and feeding on MPS are likely greatest during this time period (Churchward-Venne et al. 2012). However, recently there has been some debate over the critical nature of consuming protein immediately after exercise. Resistance exercise increases MPS for up to ~48 h (Phillips et al. 1997), indicating that consumption of dietary protein at any point within the two days following a resistance training session would likely stimulate synergistic effects on MPS similar to those observed when amino acids are provided immediately after resistance exercise. In support of this, consumption of 15 g of whey protein 24 h after a single session of resistance exercise has been shown to stimulate greater MPS than the same dose provided at rest (Burd et al. 2011). Nevertheless, the synergistic enhancement of resistance exercise-induced elevations in MPS by protein provision is likely greatest immediately post-exercise and fades over time (Churchward-Venne et al. 2012). Thus, a

simple message for strength training athletes is that protein ingestion should begin early after exercise (i.e., immediately to 2 h post-exercise) to promote recovery and possibly enhance adaptation (Phillips and Van Loon 2011).

PROTEIN QUANTITY

A classic saturable dose-response relationship has been shown to exist between protein intake and the rate of MPS following resistance exercise (Moore et al. 2009; Witard et al. 2014). Moore et al. (2009) fed isolated egg protein to young, resistance-trained males in graded quantities from 0 to 40 g immediately after a session of resistance exercise performed in the fasted state. MPS showed a dose-dependent increase from 0 to 20 g; however, doubling protein intake to 40 g did not further enhance MPS and stimulated a marked increase in whole-body leucine oxidation rates. Corroborating these data, Witard et al. (2014) recently showed that a 20-g dose of whey protein is sufficient to maximally stimulate MPS after a bout of resistance exercise performed following the consumption of a high protein breakfast, with larger doses failing to further augment post-exercise MPS and, instead, stimulating amino acid oxidation and catabolism. Taken together, these data indicate that the optimum amount of protein to consume to maximize the anabolic response after resistance exercise is approximately 20 to 25 g (8 to 10 g essential amino acids [EAA]) of high-quality protein in larger men (~85 kg). Consuming greater quantities appears to offer no further benefit in terms of MPS and results in the oxidation of the excess amino acids, which reflects greater oxidative fate of protein when the goal is to enhance gains in muscle mass. Although studies have yet to clearly establish whether the optimal quantity of protein to consume to maximally stimulate MPS after resistance exercise varies between athletes of different body weights, based on the available evidence from acute studies, a body weight corrected dose of 0.25 to 0.3 g kg^{-1} appears to be an effective amount.

PROTEIN SOURCE

Different dietary protein sources, even among those considered to be of high quality, have been shown to differ in their capacity to stimulate MPS (Figure 4.1) and promote gains in muscle mass over time in combination with resistance training (Phillips and Van Loon 2011). For example, the consumption of fat-free fluid milk following a bout of resistance exercise resulted in greater net muscle protein accretion in the hours following the exercise session compared to an isonitrogenous and isoenergetic soy beverage in young men (Wilkinson et al. 2007). When studied chronically over 12 weeks of resistance training, the repeated post-exercise consumption of fat-free milk promoted greater gains in lean body mass than did the soy beverage (Hartman et al. 2006). In addition, studies comparing the two main proteins in milk (whey and casein) have demonstrated that the whey protein fraction promotes a superior MPS response and results in greater gains in strength and muscle mass when supplemented over several weeks of resistance training (Tang and Phillips 2009). While the reasons why some high quality protein sources produce greater muscle protein accretion than others do are not entirely clear at present, it

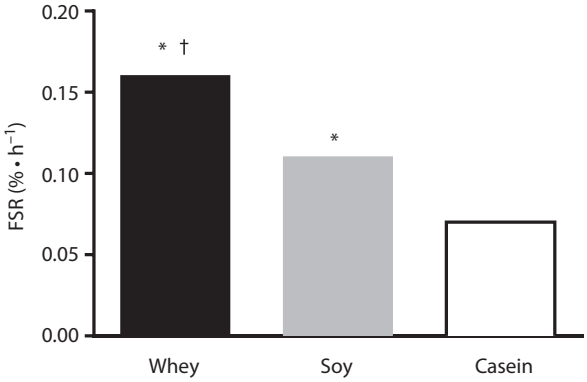


FIGURE 4.1 Mixed muscle protein fractional synthetic rate (FSR) after ingestion of 20 g of whey hydrolysate, casein, or soy protein following resistance exercise. †, Whey consumption resulted in significantly greater FSR compared to both casein and soy; *, soy ingestion resulted in significantly greater FSR than casein. (Redrawn from Tang, J.E. et al. 2009. *J Appl Physiol* 107(3):987–992. With permission.)

appears to be related to the divergent characteristics of the aminoacidemia caused by different protein sources.

An increase in plasma amino acid concentrations is a potent stimulator of MPS (Tang and Phillips 2009). Studies have shown that the achievement of a rapid and pronounced plasma concentration of EAA, particularly leucine, is associated with increased rates of MPS and anabolic cell-signaling, both at rest and following resistance exercise compared to a slow rate of appearance of these amino acids (West et al. 2011). Amino acid delivery into plasma after the consumption of a dietary protein source reflects the rate of digestion and absorption, along with its amino acid composition. While the amino acid profiles of whey and casein are relatively similar, their rate of digestion varies markedly. Whey is acid-soluble and is quickly digested, resulting in a rapid, pronounced, but transient increase in postprandial plasma EAA/leucine concentrations (Tang and Phillips 2009). Casein, on the other hand, effectively "clots" when exposed to stomach acid, slowing the rate of gastric emptying, resulting in a much more moderate but sustained rise in plasma amino acids. The superior capacity of whey to stimulate MPS over that of soy is not due to differing digestion/absorption kinetics as soy is also rapidly digested. However, the leucine content of soy compared to whey is lower, which results in a lower peak leucinemia and hence lower stimulation of MPS following the ingestion of soy vs. whey (Tang et al. 2009). The differences between whey, casein, and soy protein in terms of EAA content and blood leucine response to ingestion are illustrated in Figures 4.2 and 4.3, respectively.

While the EAA are primarily responsible for stimulating MPS, the branched chain amino acid (BCAA) leucine appears to have a particularly important role as a key metabolic regulator of MPS through activation of the mTOR pathway (Atherton et al. 2010a). When considering protein feeding strategies that will optimize the MPS response following resistance exercise, a protein source with high leucine content

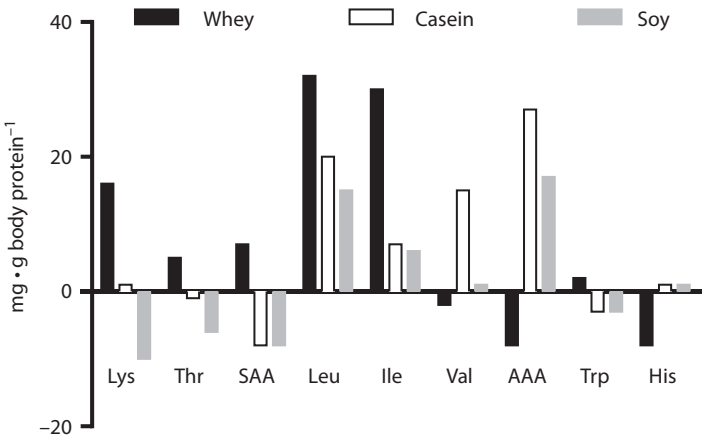


FIGURE 4.2 Differences between human body protein essential amino acid (EAA) content (FAO Expert Consultation 2013) and that of the whey, casein, and soy. The EAA content was taken from the values reported by Tang et al. (2009) for commercially available whey hydrolysate, micellar casein, and isolated soy protein. All values are in mg amino acids g^{-1} protein. AAA, aromatic amino acids; His, histidine; Ile, isoleucine; Leu, leucine; Lys, lysine; SAA, sulphur amino acids; Thr, threonine; Trp, tryptophan; Val, valine. (Adapted from Tang, J.E., and S.M. Phillips. 2009. *Curr Opin Clin Nutr Metab Care* 12(1):66–71.)

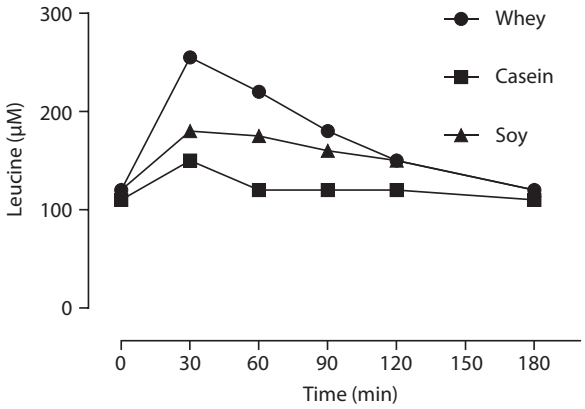


FIGURE 4.3 Blood leucine concentration after ingestion of 20 g of whey hydrolysate, casein, or soy protein. Whey consumption results in a rapid increase in blood leucine concentration, which is of greater amplitude and is considerably more rapid compared to casein and soy ingestion. (Redrawn from Tang, J.E. et al. 2009. *J Appl Physiol* 107(3):987–992. With permission.)

and rapid digestion kinetics, in order to promote a rapid leucinemia spike, would be an effective option (Churchward-Venne et al. 2012). A recent study characterizing the plasma amino acid responses to the ingestion of 20 g of protein from a range of commonly consumed protein-rich foods reported that skimmed milk produced a significantly higher and faster peak leucine concentration than all other foods or

liquids (soy milk, beef steak, egg, liquid meal supplement) (Burke et al. 2012). Peak values for EAAs, BCAA, and leucine after a soy beverage consumption tended to be lower than for the other protein sources, perhaps reflecting the lower leucine/BCAA content of soy. In addition, ingestion of liquid forms of protein achieved peak plasma amino acid concentrations twice as quickly as solid protein-rich foods (~50 min vs. ~100 min), suggesting that the form of the food may be an important determinant of post-prandial aminoacidemia. Nonetheless, more research is needed to determine the physiological relevance of food form in the regulation of MPS after resistance exercise.

In summary, current evidence suggests the type/source of protein consumed after resistance exercise influences the magnitude of the acute muscle protein synthetic response and, when practiced over time, the same acute protein turnover responses translate into longer-term phenotypic responses affecting training adaptations. The more effective protein source should have a high leucine content and rapid digestion kinetics in order to promote a rapid leucinemia spike and contain a full complement of EAA to support and sustain the protein synthetic response; proteins such as whey protein and bovine skimmed milk have been tested and fall into this category.

DISTRIBUTION OF DAILY PROTEIN INTAKE

The importance of the distribution of daily protein intake has received some attention as a potential strategy to augment muscle protein accretion. A strong rationale for considering protein distribution throughout the day comes from acute studies showing that ~8 to 10 g of EAA is sufficient to induce a maximal stimulation of MPS both at rest and after resistance exercise. Since it appears that only dietary EAA are required to maximally stimulate muscle protein synthesis, it has been suggested a balanced pattern of protein intake with consumption of 8 to 10 g of EAA at each meal would maximally and efficiently stimulate MPS on numerous occasions throughout the day. From a practical standpoint, 8 to 10 g of EAA translates into approximately 20 to 25 g of high-quality protein, which can be obtained from moderate servings of a number of protein-rich foods as shown in Table 4.1. While there is little data available on the meal-to-meal protein intakes of strength-power athletes specifically, typical eating patterns in many Western societies would consist of a skewed pattern of protein intake in which ~50% of daily protein intake is consumed at a late-day dinner-time meal and small amounts are consumed at breakfast and pre-bed. At least theoretically, consuming protein in this skewed fashion would result in a full stimulation of MPS, but also a high oxidation and catabolism of amino acids over and above the maximally stimulatory protein dose of 0.25–0.3 g protein/kg/meal, in response to the dinner meal while protein doses consumed at breakfast and pre-bed may be insufficient to maximally stimulate MPS. As mentioned previously, resistance exercise increases the sensitivity of MPS rates to dietary amino acid provision for up to 48 h after the exercise session. Thus, consuming protein in this skewed pattern may hamper adaptations to training. Providing some support for this hypothesis, it was observed that both whole body (Moore et al. 2012) and muscle (Areta et al. 2013) protein synthesis tended to be greater when 80 g of whey protein was consumed as four 20-g doses every 3 h compared to the same amount consumed

TABLE 4.1
Quantities of Some Common Foods Providing 10 g of Essential Amino Acids (EAA)

Food	Quantity Providing 10 g EAA	% Leucine (of EAA Content)
Chicken breast, baked	80 g	18
Beef, lean, roasted	100 g	21
Tuna, tinned in water, drained	95 g	19
Milk, skimmed	650 mL	21
Eggs, poached	180 g (3–4 large eggs)	19
Yogurt, plain, nonfat	360 g	21
Cheese, cheddar, reduced fat	95 g	20
Cottage cheese	170 g	21

Note: % Leucine represents proportion of EAA content accounted for by leucine. EAA/leucine content determined using Nutrition Data via USDA National Nutrient Database for Standard Reference, Release 25.

as either two large (40 g) doses every 6 h, or eight small (10 g) doses every 1.5 h over the 12-h recovery period following a session of resistance exercise. In the future, it will be important to assess whether these acute protein synthetic benefits translate into a superior adaptive response to prolonged resistance training.

It is worth noting that the muscle becomes refractory to persistent aminoacidemia (Atherton et al. 2010b), indicating the protein-containing meals should be spaced out throughout the day. In the absence of any data to provide a rationale for greater meal frequencies, 3 to 4 feedings daily seems an appropriate recommendation. A potentially important and perhaps underappreciated opportunity for strength athletes to consume a protein-rich meal is before bed. It has recently been demonstrated that the ingestion of a larger protein dose (40 g of casein) immediately before bed resulted in a greater stimulation of MPS overnight (Res et al. 2012), suggesting this may be a viable feeding strategy to optimize MPS during the otherwise fasted 8- to 10-h fast period that typically accompanies sleep. Such a pre-sleep meal would likely also facilitate recovery as it would allow repair/remodeling of proteins during the overnight period. Considering the prolonged duration of the overnight fast, larger protein doses, such as those used in the study by Res and colleagues, may be optimal in the pre-bed meal.

In summary, strength athletes should aim to consume protein in a balanced manner throughout the day, with the ingestion of ~25 g (or 0.25 to 0.3 g/kg) of high quality protein in 3 to 4 protein feedings evenly spaced throughout the day. It is notable that the available studies determining the optimal dose of protein required to maximally stimulate MPS have been conducted using either isolated protein supplements or single protein-rich foods (i.e., beef). When protein-containing foods are consumed in the context of a mixed meal, the co-ingestion of substantial amounts of other nutrients such as fat and fiber may affect rates of digestion and subsequent aminoacidemia (Burke et al. 2012). Given the role of the pattern of aminoacidemia in influencing the MPS response, further studies will have to confirm the ideal

quantity of protein athletes should consume at each mixed meal to optimize the MPS response, which is likely higher than that for isolated protein sources.

CARBOHYDRATE NEEDS

Glycogenolysis plays an important role in the production of energy during repetitive lifts in resistance training. Various studies have reported that a single resistance training session results in a 24% to 40% decrease in muscle glycogen content from relevant muscles (Slater and Phillips 2011). The extent of depletion is affected by characteristics of the training session including duration, volume, and intensity, with higher repetition, moderate-load sessions such as those undertaken during the hypertrophy phases of training programs resulting in the largest reductions in muscle glycogen stores (Slater and Phillips 2011). These results have led to the idea that carbohydrate is a potentially limiting substrate during resistance exercise workouts (Burke 2007). In support of this thesis, some studies have reported reductions in isometric strength, isokinetic force production, and workload capacity during resistance training sessions performed with compromised muscle glycogen stores (Jacobs et al. 1981), although this is not a universal finding (Mitchell et al. 1997). The variation between methods used to induce glycogen depletion between studies may, at least in part, account for the inconsistency between studies as different protocols used various combinations of exercise and dietary carbohydrate restriction. However, the current literature supports the opinion that pre-exercise muscle glycogen stores do not appear to affect brief resistance training capacity (Slater and Phillips 2011). Furthermore, when the volume and intensity of resistance exercise is matched, commencing resistance exercise with low muscle glycogen does not appear to impair the MPS response in the early recovery period (Camera et al. 2012). On the other hand, it is possible that inadequate glycogen levels will impair performance in any training session or competitive event that relies on rapid and repeated glycogen breakdown (Slater and Phillips 2011). Overall, the literature fails to provide sufficient evidence to make definitive guidelines about total carbohydrate intake for strength athletes and longitudinal studies are required to systematically investigate the influence of various levels of intake on the outcomes of a resistance training program. Because resistance training forms only one aspect of the overall training program for sprinters and throwers, and resistance exercise-induced skeletal damage impairs glycogen resynthesis, it would seem reasonable to encourage strength-athletes to consume a moderate carbohydrate intake (Slater and Phillips 2011). While carbohydrate recommendations of 6 g kg^{-1} d^{-1} for strength athletes exist in the literature, this may not be suitable for all athletes such as larger individuals with lower relative energy expenditure or females in whom high carbohydrate intakes may compromise intakes of other nutrients within a smaller energy requirement. Thus, current experts recommend daily carbohydrate intakes of 4–7 g kg^{-1} d^{-1} for strength athletes depending on their phase of training (Slater and Phillips 2011). One exception to this might be if significant reductions in body fat need to be achieved during the lead up to a strength athlete's competitive season. In this situation, there is some evidence to support carbohydrate intakes below the range recommended above (Phillips and Van Loon 2011). This is discussed further in this chapter. Finally, perhaps even more

important than total carbohydrate intake, strength-power athletes should consume carbohydrate strategically around training sessions to promote optimal carbohydrate availability at key time points for glycogen restoration (Slater and Phillips 2011).

CARBOHYDRATE AFTER RESISTANCE EXERCISE

The importance of post-exercise carbohydrate ingestion to restore muscle glycogen stores is well accepted in endurance and team sports. Considering that resistance training usually accounts for only one component of the overall training program for many strength athletes, carbohydrate should be routinely ingested after resistance training to replete glycogen levels and enhance recovery (Slater and Phillips 2011). This may be especially critical when the recovery period between resistance workouts is limited. For example, Haff and colleagues showed that carbohydrate intake during and after a resistance training session enhanced performance in a second bout of resistance exercise undertaken after a 4-h recovery period, allowing participants to complete more work in the subsequent training session (Haff et al. 1999). Co-ingesting protein with carbohydrate after resistance exercise lowers the carbohydrate intake required to replenish muscle glycogen stores. For example, the intake of 0.8 g kg^{-1} h^{-1} carbohydrate plus 0.2–0.4 g kg^{-1} h^{-1} protein results in similar rates of muscle glycogen resynthesis over 5 h of recovery as 1.2 g kg^{-1} h^{-1} carbohydrate alone following intermittent exercise, with a similar response evident after resistance exercise (Beelen et al. 2010). This reduction in post-exercise carbohydrate requirements is advantageous for strength athletes working off a tighter energy budget such as females and those aiming to reduce body fat levels.

As discussed previously, the ingestion of protein after resistance exercise stimulates muscle protein synthesis, inhibits protein breakdown, and allows for net muscle protein accretion. Carbohydrate ingestion during recovery attenuates the exercise-induced increase in protein breakdown but does not affect protein synthesis rates. This means that post-exercise intake of carbohydrate alone improves net muscle protein balance, but in order for the net balance to become positive (and for muscle protein accretion to occur) protein must be ingested (Churchward-Venne et al. 2012). In light of the inhibitory effect of carbohydrate consumption on muscle protein breakdown, a number of studies have investigated whether the co-ingestion of protein and carbohydrate after resistance exercise could enhance net muscle protein accretion over and above that of protein alone. Staples and colleagues (2011) reported that the addition of 50 g of carbohydrate to a 25-g dose of whey protein after an acute bout of resistance exercise resulted in similar rates of muscle protein synthesis and breakdown as compared to the ingestion of 25 g of whey protein alone in young men. These findings, which are corroborated by the results of a number of other studies, indicate that when protein intake is sufficient, carbohydrate does not further enhance post-exercise muscle protein turnover (Phillips and Van Loon 2011).

HYDRATION

In order to allow for the most intense training possible, strength athletes should be encouraged to undertake resistance training in a state of euhydration. This is

supported by evidence showing that when resistance training is commenced in a hypohydrated state (reduction in body weight of ~2.5% to 3%), there is a reduction in workload capacity (Kraft et al. 2012). While it may be argued that 2.5% to 3% hypohydration is unlikely to occur in an athlete undertaking a typical resistance training session, it must be acknowledged that resistance exercise forms only one component of the training program for many strength athletes. Furthermore, a substantial number of athletes, even those competing at an elite level, have been shown to arrive at training in a state of hypohydration (Maughan et al. 2004). Therefore, strength athletes should be advised to follow general hydration guidelines for all athletes (Shirreffs and Sawka 2011). This means making use of fluids during training and implementing rehydration strategies after exercise. When viewed from an integrated perspective, consumption of a liquid form of protein and carbohydrate after resistance training would provide a convenient way for strength athletes to achieve the four goals of recovery—rehydration, restoration of metabolized glycogen, restoration/repair of damaged proteins, and remodeling proteins (Phillips and Van Loon 2011). This may be particularly relevant in athletes who struggle to consume sufficient food intake post-exercise for practical or physiological reasons. Bovine fluid milk represents an excellent option for strength athletes when consumed as a post-exercise recovery drink. Consumption of milk in the immediate period after resistance exercise has been shown to augment lean mass gain over several weeks and, from a rehydration perspective, has also been shown to be equivalent or better than water and isotonic sports drinks for the restoration of fluid balance (Watson et al. 2008). While the quantity of milk required to provide ~20 g of protein (~600 mL skimmed milk provides ~30 g of carbohydrate; see Table 4.1) may not deliver sufficient carbohydrate for strength athletes in whom glycogen repletion is a priority, flavored versions of milk (i.e., chocolate), which contain added carbohydrate as a simple sugar, can be used (600 mL skimmed chocolate milk: ~20 g protein, ~70 g carbohydrate). Therefore, milk, and its flavored varieties, would be a cost-effective alternative to supplements to enhance recovery (Phillips and Van Loon 2011).

NUTRITION TO MANIPULATE BODY COMPOSITION

While the expression of strength has a significant neural component, it is also closely associated with skeletal muscle mass. Thus, muscle mass is an important determinant of performance in strength-power sports and achieving and/or maintaining gains in muscle mass represents an important goal for many of these athletes. An athlete's ability to achieve gains in lean body mass is influenced by characteristics of the resistance training program, training experience, gender, genetics, and, to some degree, nutrition (Burke 2007). Nutritional tactics proposed to support lean body mass gains include being in a positive energy balance, protein-related strategies discussed previously, and the strategic timing of carbohydrate intake around workouts.

A positive energy balance promotes an increase in body mass partitioned into lean body mass and body fat. Even in the absence of a training stimulus, overfeeding is associated with a gain in lean body mass provided that a moderate to high protein intake is consumed (Bray et al. 2012). Regrettably, most studies of caloric overfeeding have been undertaken with sedentary participants and the interaction

between overfeeding and resistance exercise on body composition has not been well characterized. The magnitude of the positive energy balance needed to maximize gains in lean body mass is an area of contention. This relates to the fact that a gain in fat mass is usually undesirable for strength and power athletes, many of whom need to maximize the ratio of strength or power to body mass (Slater and Phillips 2011). Ideally, added energy to promote positive energy balance should support gains in lean mass while minimizing gains in body fat; however, this is a hard point to define. While further study is required to determine the optimal increase in energy intake to achieve this goal, a practical target of ~500 kcal d^{-1} over requirements has been suggested by sports nutrition experts (Burke 2007). In the absence of resistance exercise, such a daily increase would theoretically result in an increase in fat mass of ~0.4 kg wk^{-1} (~1 lb wk^{-1}); however, some lean mass would also be gained (Bray et al. 2012). When calculating the increase in energy intake required, the athlete should also take into account the energy costs of additional training sessions performed to promote muscle gains. Hence, surfeit energy intakes should be equivalent to cover the energy cost of the increased training load and sufficient to promote gains in lean mass. Changes in body composition should be monitored over a sustained period and energy intake adjusted if weight gain is insufficient or if body weight gain as fat mass exceeds acceptable levels. Evidence from sedentary populations indicates that the changes in body composition induced by several weeks of positive energy balance are influenced by the protein content of the diet (Bray et al. 2012). In this study, higher protein intakes (15% to 25% of energy) were associated with greater lean body mass accrual without additional fat mass gain compared to diets lower in protein (5%) energy (Bray et al. 2012). Further work is required in resistance trained athletes to determine if protein intakes higher than 25%, which are often consumed by resistance-trained athletes, are even more effective during periods of positive energy balance in facilitating greater gains in lean body mass and muscle function while attenuating the rise in body fat. In addition, some evidence exists to suggest that longer duration weight gain periods and nutrition counseling may be advantageous in supporting lean mass gains while minimizing the impact on body fat in elite athletes (Garthe et al. 2011a).

A strategy that strength and power athletes may use to increase total energy intake is by consuming carbohydrate before, during, and after the workout. This will help the athlete to achieve a positive energy balance and, as discussed under carbohydrate needs previously, may promote better training during prolonged workouts. The consumption of protein after workouts, with attention to dose, source, and daily timing pattern, would also be a key strategy for athletes to enhance adaptations to training and promote hypertrophy over time as we have detailed under protein needs.

REDUCING BODY FAT

Olympic lifting and powerlifting are weight division sports, meaning that moderately low body fat levels are required in these athletes to optimize their power-to-body mass ratio. In bodybuilding, low body fat levels are desired during competitive periods to enhance aesthetic appearance. Thus, achieving reductions in body fat represents a common body composition target for many of these athletes. Attempts to

reduce body fat through dieting (i.e., intentional weight loss through induction of a negative energy balance) are frequently accompanied by reduction in muscle mass (Weinheimer et al. 2010). Although the performance implications of a decrease in skeletal muscle are unknown in bodybuilders, given the aesthetic component and subjective nature of the competition, the loss of skeletal muscle mass in lifters may compromise strength and therefore performance (Slater and Phillips 2011). To avoid this situation, nutritional strategies should be employed to decrease fat mass while preserving muscle. A large body of evidence shows that higher protein intakes, at the expense of carbohydrates, can enhance both the preservation of muscle mass and the loss of fat mass during periods of energy restriction (Wycherley et al. 2012). Moreover, it appears that a synergism exists between resistance exercise training and high protein intakes during weight loss, resulting in an even greater ratio of fat-to-lean mass loss when the two strategies are combined (Mettler et al. 2010). In a systematic review and pseudo-meta-analysis, Helms and colleagues (2014) recently evaluated the effects of dietary protein intake on body composition in energy-restricted, resistance-trained, lean athletes in an attempt to develop protein intake recommendations for these athletes. However, highlighting the lack of available research in this area, of the six studies included in the review, only two actually compared well-matched groups of athletes consuming different protein intakes (Mettler et al. 2010; Walberg et al. 1988). In the absence of sufficient data necessary to make a truly evidence-based recommendation, protein intakes of ~1.8–2.7 g kg^{-1} d^{-1} (or ~2.3–3.1 g kg^{-1} fat-free mass) have been proposed (Helms et al. 2014; Phillips and Van Loon 2011). In addition, a meta-analysis of randomized controlled trials (Abargouei et al. 2012) showed that hypoenergetic diets that contained a high quantity of dairy foods result in a significantly greater weight loss, fat mass reduction, and lean mass retention/gain compared to conventional calorie-restricted diets, suggesting that strength athletes may benefit from high dairy consumption. A number of bioactive components in dairy foods may contribute to this effect. For example, the amino acid leucine, which is highly enriched in milk proteins, is a potent stimulus for muscle protein synthesis and may be critically important for the muscle-sparing effect. The enhancement of fat loss may involve potential antiadipogenic and prolipolytic effects of leucine and calcium, increased fecal fat excretion, a decrease in fat absorption, and an increase in fat oxidation. Other mechanisms that may account for the efficacy of high protein diets include thermogenic and satiety-promoting effects, which are greater than are those of carbohydrate and fat (Phillips and Van Loon 2011).

The rate of weight loss (and therefore severity of energy deficit) has also been shown to influence changes in body composition and strength performance in elite athletes (Garthe et al. 2011b). Therefore, strength power athletes should allow sufficient time to achieve weight/fat loss goals, aiming for a slow rate of weight loss of approximately 0.5 kg wk^{-1} via a moderate energy deficit of ~500 kcal d^{-1} (although there will be individual differences). In order to manage recovery goals within a tight energy budget, athletes should be encouraged to time their meals so that one of the planned meals during the day coincides with the immediate post-exercise recovery period, rather than consuming an extra recovery meal (Sundgot-Borgen and Garthe 2011).

While a slow controlled loss of weight for competition or training purposes represents an ideal situation, in practice athletes and sports dietitians/nutritionists

may not always have extended periods of time available to modify body composition. Mettler and colleagues (2010) reported that consuming protein at the upper end of the acceptable macronutrient distribution ranges (AMDR) outlined by the U.S./Canadian dietary guidelines committee (i.e., 35% of dietary energy from protein) during a 2-week period of marked energy restriction (40% reduction in energy intake) resulted in the preservation of lean mass and the loss of ~1.2 kg fat mass in resistance-trained athletes. This was in contrast to a control group consuming 15% energy from protein (~1 g kg^{-1} d^{-1}) that lost similar body fat but also experienced a significant reduction in lean body mass. Of note, the preservation of lean body mass in the high protein group resulted in less absolute weight loss compared to the standard protein control group, which may need to be considered when devising nutritional plans for athletes in whom the primary goal is simply to "make weight" rather than optimizing fat-to-muscle mass ratio.

In another study, 30 days of a ketogenic diet (~22.0 g d^{-1} carbohydrate, 2.8 g kg^{-1} d^{-1} protein) combined with normal training resulted in a ~1.9 kg loss of fat mass with no loss of lean body mass and no decrements in explosive strength performance in elite male gymnasts (Paoli et al. 2012). The authors of this study reported that, at first, some athletes complained that they were unable to complete workouts, but these effects were transient and disappeared after the first week of the ketogenic diet allowing all of the athletes to train as they normally would. The authors attributed this to a keto-adaptation period of ~7 days that is required for full metabolic adjustment to the diet. As such, a ketogenic diet may not be ideal as a very short-term strategy (several days) to induce body fat/weight loss without impairing performance. In the same vein, athletes who intermittently consume carbohydrates during a ketogenic diet may reduce their ability to train effectively (Paoli et al. 2012). Thus, when adequate time is available (~30 days), very low carbohydrate ketogenic diets may be a potential nutritional strategy to achieve substantial reductions in body fat without impairing strength performance. However, further work is required to confirm the efficacy of these diets in strength power athletes and to determine the optimal dietary protocol.

In summary, in order to reduce body fat levels while preserving muscle mass in strength athletes, they should be encouraged to consume higher protein intakes ~1.8–2.7 g kg^{-1} d^{-1} (~2.3–3.1 g kg^{-1} fat free mass) that would form up to 35% of an athlete's total energy intake, while continuing to incorporate the strategies related to protein dose, source, and timing around training, which have been shown to enhance muscle hypertrophy. Ideally, athletes should assume a moderate energy restriction (energy deficit of ~500 kcal d^{-1}) to allow gradual reductions in body fat/weight (~0.5 kg wk^{-1}). However, when more rapid reductions are required, combining a more severe energy restriction with protein intakes toward the higher end of the range recommended above may help to reduce the loss of skeletal muscle. Reducing carbohydrate to ~40% of energy (with an emphasis on low GI sources) may facilitate fat loss (Phillips and Van Loon 2011). This usually means reducing carbohydrate to 3–4 g kg^{-1} d^{-1}; however, the decision regarding the level of carbohydrate restriction should be dictated by how much training performance may be compromised by consuming lower than recommended carbohydrates (Phillips and Van Loon 2011). Consuming carbohydrate strategically around workouts would help to ensure

adequate carbohydrate availability to support intense training and may potentially help to compensate for low total carbohydrate intake over the day. Severe energy restriction (<30 kcal kg^{-1} d fat-free mass) should be avoided as it is associated with menstrual dysfunction, hormonal imbalance, and detrimental effects on bone mineral density (Sundgot-Borgen and Garthe 2011). Although most of the research into the consequences of low energy availability has been conducted in females, some studies indicate that males are also at risk of adverse consequences including loss of lean mass and possibly performance decrements but also metabolically based problems (Sundgot-Borgen and Garthe 2011).

COMPETITION NUTRITION

There is little evidence that acute nutritional strategies can enhance competition performance in lifters and throwers (Slater and Phillips 2011). During competition, these athletes are provided with a designated number of opportunities to achieve a maximal weight or distance, with significant recovery between each effort. Therefore, muscle fuel reserves are unlikely to limit performance. In contrast to the throwing events, Olympic weightlifting, powerlifting, and bodybuilding are weight-category sports. While sufficient time should be allocated to achieve the specified weight-category, in practice strength athletes remain vulnerable to rapid weight loss tactics to "make weight" such as acute food/fluid restriction, resulting in a state of glycogen depletion and hypohydration (Slater and Phillips 2011). Although these tactics are usually associated with performance decrements in sports requiring a significant contribution from aerobic and/or anaerobic energy metabolism, activities requiring high power output and absolute strength characteristic of lifting competitions are less likely to be influenced by acute weight loss (Slater and Phillips 2011). Furthermore, the weigh-in is usually performed 2 h before a weightlifting competition, giving athletes time to at least partially recover from any acute weight loss strategies. Nevertheless, strength athletes should be strongly discouraged from using extreme weight loss methods that place their health at risk. In the 24 to 48 h before competition weigh-in, acute weight loss strategies that may be safe and appropriate include the use of low residue, low volume diets, and moderate fluid restriction. In combination, these strategies can safely induce a 2% to 3% reduction in body mass. However, acute weight loss strategies should always be undertaken under the supervision of a sports dietitian/sports medicine professional and should be trialed in training to ensure they are well tolerated by the athlete (Slater and Phillips 2011).

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5 Dietary Supplements for Strength Power Athletes

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INTRODUCTION

Strength power athletes, weightlifters, bodybuilders, throwers, etc., are often characterized as a group of individuals who consume an inordinate amount of dietary supplements in an attempt to augment sports performance. A related stereotype is that this group of athletes, if they believe it will improve their performance, will consume dietary supplements regardless of safety. In some cases, both of these stereotypes might be correct, which is of concern. In addition, strength and power are not exclusively a type of athlete but characteristics necessary for success in many sports. Thus, any dietary supplements alleged to improve exercise performance where strength and power are contributing factors to success are candidates for use and abuse by a large number of athletes. This chapter describes the dietary supplement intake behaviors of strength power athletes, and acts as a resource on the safety and efficacy of dietary supplements that may enhance strength and power performance during competition or training.

For a dietary supplement to be valuable for a strength power athlete, or to enhance strength and power in an athlete with other primary sporting objectives, it must

enhance performance of high-intensity exercise or improve training adaptations. Additionally, the benefit-to-risk ratio must be acceptable and the supplement must not contain any ingredients banned by sporting organizations. Where possible, this review will focus on data derived from human studies. Although studies that employ animal models offer unique perspectives, species differences in response to dietary supplements can confuse the interpretation of available research. We hope to provide the most practical recommendations possible, and so will focus on clinical trials.

DIETARY SUPPLEMENT BEHAVIORS OF STRENGTH POWER ATHLETES

Although it may sound like an easy undertaking, determining the dietary supplement behaviors of strength power athletes, or any athletes, can be very difficult. Athletes may not know what they are ingesting, due to mislabeled products (ingredients not listed, substitutions, adulterations) (Newmaster et al. 2013), multi-ingredient products, or products that are administered by coaches without appropriate athlete education. In addition, there are approximately 29,000 dietary supplements available on the U.S. market, and new products arrive regularly. Further, surveys can be fraught with issues such as recall bias that can lead to erroneous results. Designing the survey that captures all available and commonly ingested dietary supplements is a challenge. An additional challenge is how to classify the athletes by training status (e.g., Olympian vs. elite vs. collegiate vs. recreational) and how to include those who exercise intensely and may be elite, but do not participate in an organized or easily documented sport (e.g., professional footballers vs. competitive bodybuilders vs. military warfighters vs. health club members). This review is not meant to summarize the use of all dietary supplements by athletes or by strength power athletes. Only a small number of dietary supplements may be beneficial for strength power athletes, or for athletes for whom strength and power is an important component of their performance or training. These include creatine monohydrate, sodium bicarbonate, β-alanine, protein and amino acids, β-hydroxy β-methyl butyrate (HMB), caffeine, and carbohydrate. This review will focus on these compounds.

Reportedly, dietary supplement use in the general population is as high as 50% in the United States; supplement use appears to be higher in elite athletes. In a review, Maughan et al. (2007) cited data from the International Association of Athletics Federations that suggests dietary supplement use by athletes is about 86% (range 77% to 89%). About 53% used non-vitamin/mineral supplements that could potentially have an ergogenic effect on strength and power performance, such as creatine, protein, and caffeine (Maughan et al. 2007). No obvious differences in dietary supplement use were evident between elite strength power (e.g., 89% of jumpers) and endurance athletes (89% of race walkers). Across all categories of Canadian Olympians, 69% and 74% used some type of dietary supplements at the Atlanta and Sydney Olympic Games, respectively (Huang et al. 2006). Huang et al. (2006) reported that the use of nutritional (non-vitamin/mineral) dietary supplements at these Olympic Games was 39% and 43%. Creatine was the most commonly used non-vitamin/mineral supplement consumed in 1996 (14%), which decreased to 12% in 2000. Conversely, protein and amino acid use increased from 3% to 13% and 7% to 15%, respectively, from 1996 to 2000. The authors observed that dietary

supplement use was higher in individual vs. team sport athletes, regardless of the nature of the sport, which is something that should be addressed in future studies.

Heikkinen and colleagues (2011) reported a decrease in dietary supplement use between 2002 and 2009 in a large sample of Finnish Olympians. Total dietary supplement use decreased from 82% to 73%, and non-vitamin/mineral dietary supplement use decreased similarly from 60% to 52%. Consumption of dietary supplements related to strength and power performance decreased significantly or tended to decrease, including protein (47% to 33%), carbohydrates (24% to 16%), and creatine (16% to 8%). Only amino acid ingestion increased (4% to 7%). In speed and power athletes, creatine use was 35% in 2002, decreasing to 19% in 2009. Team sport athletes ingested less creatine at both time points (11% and 6%). Lun et al. (2012) reported similar supplement use (87%) between a large sample of high performance Canadian athletes (n = 440; 76% national/international level) and a subset of power athletes (91%). Interestingly, dietary supplement use in endurance athletes within this sample was also similar (91%). Power athletes reported taking dietary supplements to increase lean mass or strength (16%) and to enhance recovery (18%). Less than half (40%) of power athletes reported attendance at some type of dietary supplement workshop, indicating a lack of formal education on the use of sports supplements.

Froiland et al. (2004) reported on dietary supplement use in 203 non-endurance sport Division I collegiate athletes. Eighty-nine percent were current or former supplement users, with energy drinks (74%), protein (48%), creatine (37%), caffeine (11%), and HMB (8%) use reported. About 43% took supplements to improve strength and power and about 43% for weight or muscle gain. Goston and Correia (2010) reported dietary supplement intake in 1102 health club members from 50 gyms in Belo Horizonte, Brazil. Most participants performed strength training (83%), and about half of them (46%) exercised to improve muscle strength or mass. Only 36% of all gym members reported supplement use (28% of women; 45% of men), but 58% of users ingested supplements related to strength and power development (i.e., creatine, protein/amino acids, HMB). When analyzed individually, use of these supplements seemed low compared to competitive athletes (8% creatine, 6% branched chain amino acids [BCAAs], 1% HMB).

The prevalence of dietary supplement use in elite athletes appears higher than the general population. Elite athletes commonly ingest dietary supplements to increase strength/power or gain lean mass/weight. As dietary supplement adulteration, substitution, and contamination is a real problem (see Chapter 8), strength and power athletes should be made aware of the benefit-to-risk ratio of dietary supplement use. The following section summarizes published data on the small number of dietary supplements that may be beneficial for strength power athletes, or for athletes for whom strength and power are important components of their performance or training. Additionally, risk of adverse events documented through research is discussed.

CREATINE MONOHYDRATE

Creatine is a non-essential nutrient that is produced in the body (≈1 to 2 g/d) and consumed in the diet through the consumption of meat, poultry, and fish (3 to 4 g creatine/kg meat). About 95% of creatine is stored in skeletal muscle (124.4 mmol/kg dry muscle [dm] total creatine; 49 mmol/kg dm free creatine; 75.5 mmol/kg dm

phosphorylcreatine) (Harris et al. 1974), where it is used to sustain adenosine triphosphate (ATP) levels during times of high energy need. The creatine kinase energy system, where phosphorylcreatine donates its phosphate to adenosine diphosphate (ADP) to remake ATP, can maintain ATP levels for about 8 to 10 sec at maximal exercise intensity. Muscle creatine is degraded non-enzymatically to creatinine and excreted in the urine.

In 1993, Harris et al. (1992) published a seminal paper describing increased muscle creatine levels following creatine monohydrate ingestion. These data have been validated many times over the years using either the muscle biopsy technique or nuclear magnetic resonance spectroscopy. On average, creatine monohydrate supplementation results in about a 20% increase in muscle creatine. Increased muscle creatine levels can be achieved with a short-term high-dose protocol (about 20 g/d for about 5 d) or a longer-term lower-dose protocol (about 3 g/d for about 30 d), and muscle creatine uptake can be enhanced in the presence of exercise, insulin, carbohydrate, or combined carbohydrate and protein (reviewed by Gualano et al. 2012). It appears that elevated muscle creatine levels can be maintained indefinitely with a small daily dose (2 to 5 g), but this cannot be confirmed as there are few studies lasting longer than several weeks. Both high- and low-dose protocols result in an increase in the performance of brief high-intensity exercise, particularly when there are repeated bouts (Gualano et al. 2012; Rawson et al. 2011).

The effects of creatine monohydrate supplementation on exercise performance have been investigated in hundreds of studies and have been extensively reviewed (Branch 2003; Gualano et al. 2012; Rawson and Volek 2003; Volek and Rawson 2004). In a meta-analysis, Branch (2003) concluded that creatine monohydrate supplementation improves the performance of brief (<30 sec), high-intensity exercise, especially when there are repeated bouts. Whether creatine monohydrate can benefit a strength power athlete depends on training/competition exercise intensity and duration. The magnitude of the effect of creatine monohydrate supplementation on sports performance is small in absolute terms, but significant to an elite athlete; for example, a decrease of 0.9 sec in a 100-m sprint or a 1.8 sec decrease in two successive 100-m swims (Gualano et al. 2012). Table 5.1 depicts the effects of creatine supplementation on performance as a function of exercise intensity and time.

In a review, Rawson and Persky (2007) highlighted the mechanisms through which creatine monohydrate supplementation potentially exerts an ergogenic effect. These include adaptations that occur before (increased muscle phosphorylcreatine and glycogen), during (increased phosphorylcreatine resynthesis rate), and after (reduced inflammation/muscle damage, increased expression of growth factors, lower protein degradation) exercise, potentially causing a spontaneous increase in training volume. In fact, the greatest benefit of creatine monohydrate supplementation for the strength power athlete is, perhaps, improved performance during strength and conditioning outside of competition. In a narrative review, Rawson and Volek (2003) reported a greater increase in strength and resistance exercise performance when creatine supplementation was combined with resistance training, compared to resistance training and placebo ingestion (see Figures 5.1 and 5.2).

The safety of creatine monohydrate ingestion has been well addressed and better studied than most sports dietary supplements (Gualano et al. 2012; Lopez et al. 2009; Persky and Rawson 2007). It appears that when recommended doses are ingested,

TABLE 5.1
Effects of Creatine Supplementation on Performance as a Function of Exercise Intensity and Duration

Variable	Effect
ATP-PCr system (≤300 s)	
Arm ergometry	↔
Bicycle ergometry	↑
Isokinetic torque production	↑
Isometric force production	↑
Isotonic strength	↑
Jumping	↑
Sprint running	↑
Speed skating	↑
Swimming	↑
Glycolysis (30–150 s)	
Bicycle ergometry	↑
Isokinetic torque production	↔
Isometric force production	↑
Isotonic strength	↑
Jumping	↔
Kayaking	↔
Sprint running	↔
Swimming	↔
Oxidative phosphorylation (>150 s)	
Bicycle ergometry	↑
Isokinetic torque production	↔
Isotonic strength	↔
Kayaking	↔
Sprint running	↔
Swimming	↔/↓
Rowing	↔

Source: Adapted from Gualano, B. et al. 2012. *Amino Acids* 43(2):519–529 and based on the meta-analysis from Branch, J.D. 2003. *Int J Sport Nutr Exerc Metab* 13(2):198–226.

Note: ↔ no effect, ↑ improvement, ↓ impairment.

creatine monohydrate is safe in terms of muscular, cardiovascular, renal, hepatic, and thermoregulatory function. Of greater importance is the proliferation of "novel" creatine supplement products sold under the premise of increased absorption, greater muscle uptake, and larger improvements in exercise performance relative to creatine monohydrate (Jäger et al. 2011). There appear to be no data to support such claims, which is not surprising as the absorption of creatine monohydrate is approximately 100%. More worrisome is the fact that unlike creatine monohydrate, safety data are

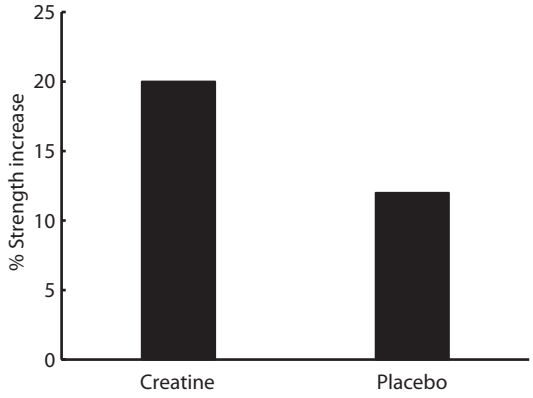


FIGURE 5.1 Effects of creatine supplementation and concurrent resistance training on maximal strength (1-, 3-, and 10-RM). (Adapted from Rawson, E.S., and J.S. Volek. 2003. *J Strength Cond Res* 17(4):822–831.)

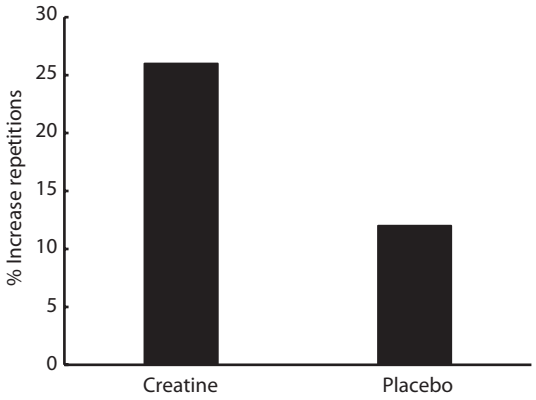


FIGURE 5.2 Effects of creatine supplementation on resistance exercise performance (repetitions at a given percentage of maximal strength). (Adapted from Rawson, E.S., and J.S. Volek. 2003. *J Strength Cond Res* 17(4):822–831.)

scant or completely unavailable for these products. In fact, some of these products contain little creatine, or appear to be pro-creatinine, and do not increase muscle creatine levels (Giese and Lecher 2009; Harris et al. 2004). If a strength and power athlete chooses to use creatine supplements, there is no reason for him or her to use a non-creatine monohydrate product.

BUFFERS

The effects of sodium bicarbonate ($NaHCO_3$) supplementation on exercise performance have been well studied and reviewed in both meta-analytic (Carr et al. 2011;

Matson and Tran 1993; Peart et al. 2012) and narrative (Jones 2014) formats. Intense exercise increases H^+ accumulation, potentially reduces force production, and hastens fatigue. $NaHCO_3$ is a buffer and, when ingested in high enough doses, can increase the bicarbonate $\left(HCO_3^-\right)$ concentration of the extracellular fluid from 25 to 30 mmol/L, which can slow acidosis-related fatigue (Jones 2014). Over two decades ago, Matson and Tran (1993) conducted a meta-analytic review of 29 investigations into the effects of $NaHCO_3$ supplementation on anaerobic exercise performance. They reported an effect size of 0.44, which is possibly a 0.8-sec improvement in a 1-min race. More recently, Peart et al. (2012) reported a slightly smaller effect size (0.36) in a meta-analysis of 40 studies, and Carr et al. (2011) demonstrated a 1.7% improvement in performance during a 1-min sprint in their meta-analysis. Thus, there is convincing evidence of a small benefit of $NaHCO_3$ supplementation on the performance of brief intense exercise. Although the benefits of $NaHCO_3$ ingestion are typically small, they can be very meaningful for an elite athlete. One unanswered question that remains is whether trained and untrained subjects experience similar benefits of supplementation, as both theories have been put forth (Carr et al. 2011; Peart et al. 2012).

$NaHCO_3$ ingestion of 0.3 to 0.5 g/kg body mass 1 to 2 h before exercise is a prudent recommendation, but athletes should practice supplementation strategies outside of competition. $NaHCO_3$ supplementation is well known to cause gastrointestinal disturbances in as much as 50% of research volunteers, which could be detrimental to performance. To maximize the benefit-to-risk ratio, it appears best to ingest $NaHCO_3$ in serial doses in combination with a carbohydrate meal or snack. In fact, it has been recommended that $NaHCO_3$ be ingested over 3 to 5 days at a dose of 100 to 150 mg/kg body mass. As Jones (2014) has noted, this might be best for athletes who have multiple events in the same day or over several days. Although acute $NaHCO_3$ supplementation has proven successful as an ergogenic aid in sprinting type activities lasting 1 to 7 min, there are few studies of $NaHCO_3$ supplementation with resistance training outcomes. Both Carr et al. (2013) and Duncan et al. (2014) reported improved resistance exercise performance (i.e., increased repetitions) following acute $NaHCO_3$ supplementation. This introduces the concept of more prolonged supplementation, which could improve resistance-training adaptations, and subsequently sports performance. However, this remains to be seen. Strength power athletes attempting to improve sports performance and athletes attempting to improve strength and power outcomes in the weight room should consider the benefit-to-risk ratio (improved performance vs. gastrointestinal distress) and whether their sport or training program supports a use for an enhanced buffer system based on exercise intensity (maximal vs. submaximal) and duration (1 to 7 min vs. less than 1 min).

Much like HCO_3^- is a strong extracellular buffer, the dipeptide carnosine (β-alanyl-L-histidine) is a robust intracellular buffer. Carnosine is more highly concentrated in type II vs. type I fibers, in sprinters vs. marathon runners, and in animals that rely heavily on anaerobic energy production for hunting or fleeing (e.g., canines, deer) or surviving under hypoxic conditions (e.g., whales) (reviewed in Harris et al. 2012). Additionally, muscle carnosine content may increase with sprint exercise training, but this has not been shown in every case. As plasma carnosine is quickly hydrolyzed

by carnosinase in humans, carnosine supplementation as a means to increase muscle carnosine content is likely ineffective. However, the amino acid β-alanine, which is the limiting factor in endogenous carnosine synthesis, can be used to increase muscle carnosine content (Figure 5.3).

As with creatine monohydrate supplementation, the seminal research on β-alanine supplementation was conducted by Harris and colleagues (2006). Since 2006, research on β-alanine supplementation increased exponentially, and meta-analytic (Hobson et al. 2012), systematic (Quesnele et al. 2014), and narrative reviews have been published (Artioli et al. 2010; Harris and Sale 2012; Sale et al. 2010, 2013). Hobson et al. (2012) analyzed the results of 15 studies and reported a 2.85% improvement in performance following β-alanine supplementation. Thus, much like creatine monohydrate and $NaHCO_3$ supplementation, there appears to be a small absolute effect, but one that could be very meaningful to an elite athlete. In practical terms, time in a 1500-m run (about 4 min) could potentially be reduced by as much as 6 sec (Hobson et al. 2012), but an effect of this size is doubtful in an elite athlete. Interestingly, Hobson et al. (2012) separated performance outcomes into three distinct time periods, and found that exercise lasting >240 sec and from 60 to 240 sec was improved with supplementation, but there was no benefit in tasks lasting less than 60 sec. This makes sense, as the cause of fatigue in exercise lasting less than

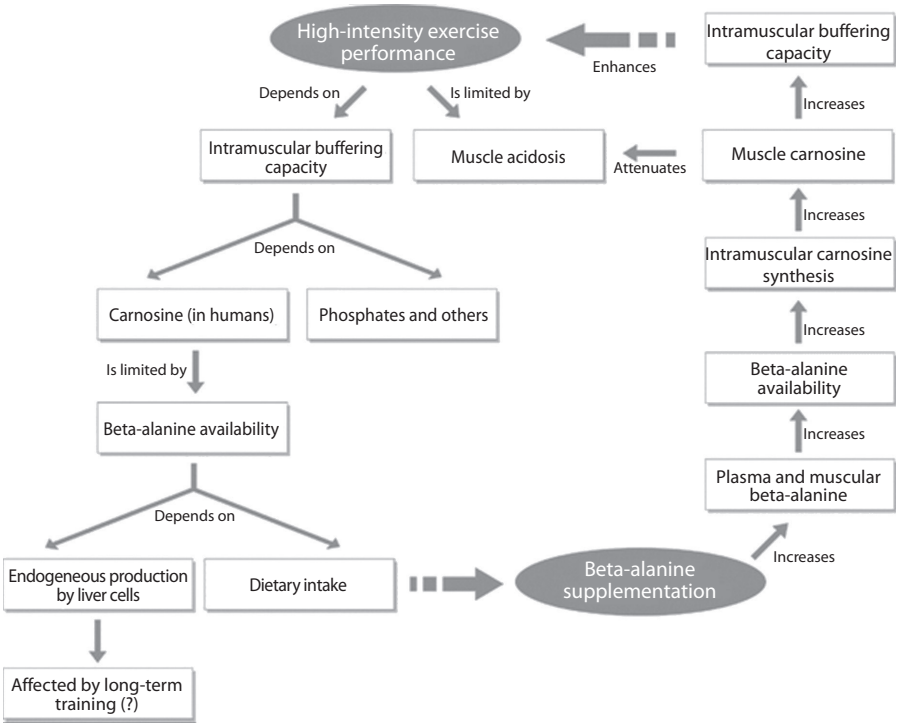


FIGURE 5.3 Overview of the role of β-alanine supplementation on high-intensity exercise performance. (From Artioli, G.G. et al. 2010. *Med Sci Sports Exerc* 42(6):1162–1173. With permission.)

60 sec is unlikely to be severe acidosis. Although β-alanine supplementation can increase power output in certain intense exercises, whether it can improve resistance exercise performance like creatine monohydrate is unclear (Kendrick et al. 2008). Any benefits on resistance training outcomes are likely dependent on the nature of the training program (repetitions, volume, rest periods, etc.).

In a systematic review of 19 studies, Quesnele et al. (2014) reported a range of supplement doses of 2.0 to 6.4 g per day for durations of 4 to 13 weeks. Although an exact recommended dose is currently unknown, a sensible supplementation regimen supported by research is 3 to 6 g per day for 4 to 8 weeks (Jones 2014). This appears adequate to increase muscle carnosine content by about 40% to 50%, and these levels remain elevated for about 10 to 15 weeks after supplementation is discontinued. There are few data on the safety of β-alanine supplementation; however, as it is an amino acid, serious adverse events would not be expected. The only known side effect to date is paresthesia (flushing), but this appears to have been resolved with timed-release supplements.

PROTEIN AND AMINO ACIDS

Dietary protein is made up of 20 different amino acids consisting of 9 essential amino acids (EAA), 3 of which are BCAAs, and 11 nonessential amino acids (NEAA). A complete review of the biochemistry of protein is beyond this chapter, which focuses on supplementation. A more detailed review of the effects of protein and amino acids is available in Chapter 4.

The recommended dietary allowance (RDA) of protein for adults is 0.8 g/kg body mass/d. It has been demonstrated, on many occasions, that this is not adequate to support the needs of intensely training athletes. The recommended intake of protein for strength power athletes is generally about 1.6 to 1.7 g/kg/d, or about twice the RDA. However, it appears that strength power athletes easily achieve at least this much in the diet (reviewed in Slater and Phillips 2011), with some ingesting as much as 3.2 g/kg/d (Chen et al. 1989). Fox and co-workers (2011) reported that collegiate male athletes are either completely unaware of the current protein intake recommendations (67%) or perceive them to be higher than they actually are (8.7 g/kg/d). The ingestion of dietary protein above 1.7 g/kg/d results in increased amino acid catabolism and protein oxidation and does not encourage greater muscle hypertrophy (Moore et al. 2009).

Muscle protein synthesis is increased following ingestion of an intact protein or a mixture of amino acids. Immediately following exercise, the consumption of about 20 g of protein (with about 8 to 10 g of EAA) is recommended to maximally stimulate protein synthesis, while increasing this amount to 40 g only serves to increase leucine oxidation (Moore et al. 2009). To promote protein synthesis throughout the day, consuming 0.25 to 0.30 g of protein/kg body mass/meal (about 20 to 25 g/meal) is recommended. In terms of protein type or quality, athletes should ingest proteins that have high levels of EEAs, in particular leucine, which are necessary for the best stimulation. In addition to EEA and leucine content, it appears that rate of digestion is an important factor in optimizing protein synthesis. For instance, Tang et al. (2009) reported that whey protein increased muscle mixed protein synthesis 93%

more than casein and 18% more than soy under resting conditions, and 122% and 31% more than casein and soy, respectively, after resistance exercise. Recently, van Loon and colleagues (Beelen et al. 2008; Res et al. 2012; van Loon 2013) reported that the consumption of protein following an evening training session was only enough to optimize protein synthesis acutely, and that overnight recovery was suboptimal. This group demonstrated a 22% higher rate of muscle protein synthesis during the overnight period with the consumption of 40 g of casein protein 30 min before sleep (Res et al. 2012). More research needs to be conducted, and long-term data are unavailable, but if a strength power athlete is training intensely, bedtime protein ingestion may help optimize overnight protein synthesis and help improve training adaptations.

A recent meta-analysis of 22 studies revealed that prolonged resistance training (>6 weeks) combined with protein supplementation resulted in larger increases in fat-free mass (38%), type I muscle fiber cross-sectional area (CSA) (45%), type II muscle fiber CSA (54%), and 1-RM leg press strength (20%) compared to training with placebo ingestion (Cermak et al. 2012). Thus, it appears that protein ingestion is a safe and effective way for strength power athletes to optimize recovery from, and adapt to, intense exercise training. Protein supplements appear beneficial, but whether they are necessary is unknown, especially given that most strength power athletes appear to ingest adequate protein. However, in terms of optimizing timing (consume immediately post-exercise, every 3 to 4 h, and before bedtime) and convenience, protein supplements provide an important nutritional option for strength power athletes. It is best if athletes viewed protein supplements as "supplements," and high protein foods as sources of EAAs as well as other important essential nutrients such as iron, zinc, and fatty acids.

β-HYDROXY β-METHYLBUTYRATE (HMB)

HMB is a metabolite of the EAA leucine. Much of the research on HMB supplementation focuses on the effects of HMB on body composition of farm animals (i.e., broiler chickens, cows, pigs, etc.). Since 1996, about 40 human supplementation studies have been published, and narrative (Zanchi et al. 2011) and systematic (Molfino et al. 2013) reviews are available. HMB, like leucine, is anti-catabolic, and can potentially decrease protein breakdown and muscle damage caused by stressful exercise. This would make HMB a valuable supplement for recovery from intense training or competition. The literature on HMB, however, is more difficult to interpret than for other strength power supplements.

Early studies and a meta-analysis (Nissen and Sharp 2003) of nine studies indicated that HMB supplementation reduced muscle damage and increased strength and lean mass. This analysis and early studies have been criticized because the nine studies were essentially completed by three groups. Additional criticisms were use of unreliable markers to assess muscle damage (e.g., creatine kinase instead of force production), overlooking the repeated bout effect (i.e., muscle damage decreases with training) in trained subjects, and failure to disclose conflicts of interest (financial relationships and patents). More recently, Molfino and colleagues (2013) analyzed 22 studies of HMB supplementation in healthy young adults, and reported that HMB

supplementation increased fat-free mass in 4 of 10 studies and strength in 7 of 14 studies. Recommended daily dosage of HMB is about 3 g per day, and although it appears safe, there are few safety data available. HMB, like creatine monohydrate, may benefit older adults or individuals with certain atrophic diseases; however, unlike creatine monohydrate, the benefits of HMB for strength power athletes are unclear. In terms of sales, HMB has not experienced the same popularity as creatine monohydrate, protein, and β-alanine in strength power athletes. It is unclear if trained or untrained individuals benefit more from HMB ingestion, but it has been proposed that HMB supplementation would be more beneficial for beginning than for advanced trainers.

Recently, Wilson et al. (2014) reported greater increases in lean mass (7.4 vs. 2.1 kg), total strength (bench press + squat + deadlift) (77 vs. 25 kg), and power (991 vs. 630 watts) in HMB-Free Acid (HMB-FA) vs. placebo supplemented subjects following 12 weeks of resistance exercise. These results are promising, but gains such as these in trained subjects rival the improvements acquired from high dose testosterone administration (HMB-FA supplementation [3 g/d for 12 weeks] plus resistance training = 7.4 kg increase in lean mass; testosterone enanthate supplementation [600 mg/week for 10 weeks] plus resistance training = 6.1 kg increase in fat free mass [Bhasin et al. 1996]) in untrained subjects. Wilkinson and colleagues (2013) reported that consumption of about 3 g of HMB-FA stimulated muscle protein synthesis, increased anabolic signaling, and attenuated muscle protein breakdown, which highlights the mechanism through which HMB supplementation might alter lean mass during resistance exercise. Although promising, research on HMB-FA is in its infancy, and much more work needs to be done before it can be recommended.

CAFFEINE

As a potential ergogenic aid, caffeine (1, 3, 7-trimethylxanthine) has been studied for over a century, and today is a common ingredient of energy drinks and many pre-workout supplements. Most research has focused on the effects of caffeine supplementation on submaximal and endurance-based performance, with the majority of studies supporting a positive effect on such activities (Ganio et al. 2009; Spriet 2014). There is also evidence that caffeine supplementation enhances short duration, high intensity, anaerobic-based exercise, which would benefit the training or competition of many strength power athletes (Astorino and Roberson 2010; Davis and Green 2009; Spriet 2014; Warren et al. 2010).

In a review article on caffeine and anaerobic exercise performance, Davis and Green (2009) concluded that caffeine ingestion was most beneficial for speed endurance activities when the duration of the activity lasted between 60 and 180 sec. However, short duration activities (4 to 6 sec) can also be benefited when the activities are more sport specific. For instance, in a simulated rugby game, Stuart et al. (2005) demonstrated an improvement in sprint speed, agility performance, peak power, and throwing accuracy in male rugby players who ingested caffeine (6 mg/kg) compared to those who ingested placebo. Caffeine is likely also ergogenic to other team sports such as soccer, lacrosse, and football, with 65% of studies using team sports or power and sprint performance outcomes supporting significant improvements ranging from 1.0% to 20.0% (reviewed by Astorino and Roberson 2010).

There is some evidence that caffeine can benefit both muscular strength (1-RM, 3-RM, etc.) and resistance training performance (repetitions to failure at a given percentage of maximum or lifting volume), although these have not been unanimous outcomes (Astorino and Roberson 2010; Davis and Green 2009). A recent systematic review reported that 6 out of 11 studies supported a significant benefit to resistance training with a mean improvement of 9.4% (Astorino and Roberson 2010). It was also estimated that caffeine supplementation improved resistance training performance (measured by repetitions completed) more than muscular strength (measured by 1 or 3-RM). One study supported an increase in both 1-RM and repetitions to failure at 60% of 1-RM in collegiate male athletes following consumption of a moderate dose of caffeine (5 mg/kg) (Duncan and Oxford 2011). Therefore, there is some evidence to suggest that caffeine ingestion prior to resistance training may provide some advantages; however, more research is needed on the topic.

A full understanding of caffeine's mechanisms of action is currently unknown, although evidence suggests that multiple mechanisms are involved. It has been proposed that caffeine improved exercise performance by increasing the oxidation of fat and decreasing carbohydrate metabolism through a negative feedback loop, but this has been a controversial theory over the years and is no longer thought to be the primary mechanism of action (Spriet 2014). Further, even if caffeine supplementation resulted in glycogen sparing and increased fat oxidation during exercise, it would not explain performance enhancements that would occur during short-term high-intensity exercise. Caffeine is a powerful central nervous system stimulant, increases alertness, and may reduce perceived exertion and decrease pain perception (Astorino and Roberson 2010; Davis and Green 2009). In addition, caffeine can enhance Ca^{2+} release from the sarcoplasmic reticulum, excitation contraction coupling, force production, and motor unit recruitment (Warren et al. 2010).

Low to moderate doses of caffeine ranging from 2.5 to 7 mg/kg have been shown to be ergogenic for a variety of strength and power outcomes including resistance training, sprinting, agility, and sport-specific measures (Astorino and Roberson 2010; Sokmen et al. 2008; Spriet 2014). When caffeine is consumed from sources such as energy drinks, supplements, or gum, doses as low as 1.0 to 2.5 mg/kg are sufficient to improve performance; however, it appears that larger amounts are needed when only caffeine is consumed (Astorino and Roberson 2010). In addition, while low to moderate doses may provide optimal benefits, doses in excess of 6 to 9 mg/kg typically result in adverse effects such as jitters, tachycardia, anxiety, restlessness, insomnia, headaches, and performance decrements.

Plasma concentration levels peak between 30 and 60 min post-consumption, with benefits disappearing approximately 6 h after acute ingestion. Therefore, caffeine should be taken no sooner than 3 h before strength and power events to maximize benefits (Sokmen et al. 2008). Caffeine tolerance may blunt the effects of caffeine, and so habitual caffeine users may choose to withdraw from caffeine prior to an athletic event to maximize benefits. Caffeine withdrawal should begin a minimum of 1 week prior to competition with caffeine intake being slowly decreased over 3 or 4 days to reduce negative effects and training decrements, which can result from an abrupt cessation of caffeine use (Sokmen et al. 2008). Returning to normal levels of caffeine intake on the day of the athletic event will again provide an enhanced ergogenic effect.

CARBOHYDRATE

The ergogenic effects of carbohydrate ingestion for endurance athletes are well known. However, carbohydrate ingestion may be important for strength power athletes as well. High volume resistance training significantly decreases muscle glycogen content, which could increase fatigue and lead to deficits in performance (MacDougall et al. 1999; Robergs et al. 1991; Tesch et al. 1998). Muscle glycogen stores are reduced 20% to 40% during an acute bout of resistance exercise (MacDougall et al. 1999; Tesch et al. 1998), and carbohydrate restriction leads to a decrease in resistance exercise performance (Leveritt and Abernethy 1999). The hypertrophy or endurance phase of some athletes' resistance training programs is characterized by 3 to 20 repetitions, 3 to 5 sets, and 3 to 4 days per week, which relies heavily on carbohydrate for fuel. With that in mind, several research groups have examined the effects of carbohydrate ingestion on strength and power related outcomes (Haff et al. 1999, 2000, 2001; Lambert et al. 1991) (reviewed in Haff et al. 2003).

Carbohydrate (CHO) supplementation prior to (1.0 g CHO/kg body mass) and during (0.17 g CHO/kg body mass) resistance exercise enhanced resistance exercise performance by enabling more sets (+2.7) of leg extensions performed to volitional fatigue (80% of 10-RM) (Lambert et al. 1991). Also, carbohydrate ingestion prior to (1.0 g CHO/kg body mass) and in between sets (0.51 g CHO/kg body mass) increased work and torque during 16 sets of isokinetic leg extensions (10 reps at 120°/s) (Haff et al. 2001). Significant improvements in performance were also seen with consumption of 1.2 g CHO/kg body mass during and between multiple training sessions in one day, resulting in more sets, repetitions, and delayed muscular fatigue (Haff et al. 1999). Conversely, Haff et al. (2000) reported that carbohydrate supplementation prior to (1.0 CHO/kg body mass) and every 10 min during (0.51 g CHO/kg body mass) a 39-min resistance exercise bout did not improve isokinetic leg exercise performance (3 sets of 10 repetitions at 120°/s). Similarly, carbohydrate ingestion of 0.3 g/kg body mass before and after every set of five repetitions at 85% 1-RM did not improve performance or delay fatigue (Kulik et al. 2008).

The characteristics of a resistance exercise training program (intensity, duration, volume, etc.) influence the rate of glycogenolysis (Robergs et al. 1991) and may explain some of the discrepant findings in this small body of literature. For instance, the exercise completed in the studies where carbohydrate ingestion successfully improved resistance exercise performance tended to be longer in duration (56 to 77 min) than those where there was no ergogenic effect of the carbohydrate (28 to 39 min). Unfortunately, there are few studies of the effects of carbohydrate on strength power outcomes and resistance exercise performance, and they are difficult to compare due to differences in supplementation and exercise protocols. More research is warranted to establish the impact of carbohydrate supplementation prior to and during high intensity anaerobic activities such as resistance training.

CONCLUSION

Although the foundation for success in sports continues to be optimal diet and training, there are a small number of dietary supplements that appear to be worthwhile for

strength power athletes. Supplements that appear to have a sensible benefit-to-risk ratio include creatine monohydrate, protein, and caffeine, and potentially beta-alanine, sodium bicarbonate, HMB, and carbohydrate. Collectively, these supplements may enhance strength and power performance in the weight room or on the playing field, or enhance recovery from stressful exercise. As with all dietary supplements, consumers must be conscious of quality control issues, legality, and the rules of their sporting organizations. Not enough data are available to conclude if the dietary supplements described in this chapter benefit elite athletes more than beginning or intermediate exercisers. In either scenario, the absolute benefit will be small. The supplements described in this review all work through different mechanisms and pathways, suggesting that their effects may be additive. While this is an alluring thought, and there is some evidence that the combination of some of these supplements may be more beneficial than ingestion of any one individual supplement, there are few data available. Overall, after taking into account the specifics of their sport, training, and diet, it appears that certain dietary supplements may be of benefit to strength power athletes. Athletes should be reminded that dietary supplements are just that, supplements to the diet, and that a poor diet or suboptimal training will place them at a far greater disadvantage than the absence of a particular sports supplement.

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