Journal of Strength and Conditioning Research, 1995, 9(2), 116-124

A Review of Nutritional Practices and Needs of Bodybuilders

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Reference Data
Walberg-Rankin, J. A review of nutritional practices and needs of bodybuilders. *J. Strength and Cond. Res.* *9(2):116-124. 1995.*

ABSTRACT

This paper reviews (a) what has been reported concerning the diets of bodybuilders and (b) the evidence for differences in their nutrient requirements. The literature shows that bodybuilders tend to consume a high energy/high protein diet with moderate fat and carbohydrate during training when their goal is to increase lean body mass. In preparing for competition, when the goal is to reduce body fat, bodybuilders have reported consuming a reduced energy diet with very low fat and high protein. Most of the studies reported that carbohydrate intake was modest, although carbohydrate loading a few days before a contest was mentioned. Some research has identified unique nutrient needs for bodybuilders, including an increase in dietary energy and protein. Consumption of carbohydrate before and after a workout may enhance the workout as well as the recovery afterward. It is recommended that bodybuilders regularly consume a high energy diet with protein in the 1.2 to 2.0 g · kg^{-1} range, with approximately 60% of energy as carbohydrate. A similar diet but with moderately restricted energy should be consumed when preparing for a competition to minimize reduction in lean body mass and muscle performance.

Key Words: resistance exercise, nutrition and athletes, dietary intake, protein requirement, weight loss

Introduction

Much work has been done describing the nutritional needs and habits of endurance athletes. Less is known about the potentially unique practices and requirements of those involved in activities such as bodybuilding. The physical training of bodybuilders primarily involves high volume resistance weight training. Their goal is to increase muscle mass and symmetry and minimize body fat. The latter is often emphasized in the months prior to competition and is referred to as the "cutting" phase. This review will summarize the studies that have described the dietary habits of bodybuilders in training and preparing for competition, and will discuss the evidence for increases in requirement for a variety of nutrients.

I. What do Bodybuilders Eat?

Diet During Training

Resistance weight training is an anaerobic activity that typically uses less energy over a workout period than does continuous aerobic activity. However, reports of the energy intake of male bodybuilders show that they are consuming amounts similar to those of many endurance athletes. Table 1 shows average energy intake reported in various studies for male bodybuilders. The male bodybuilders studied consumed between 3,500 and 4,800 kcal · d^{-1} (39 to 60 kcal · kg^{-1}) during training periods.

There was only one published report of the energy intake of female bodybuilders that claimed to be during a noncompetitive period of the year (16). Diet records indicated that their average intake was relatively modest, at 1,630 kcal · d^{-1} (28 kcal · kg^{-1}). However, these women were studied between 6 and 17 weeks before a competition. Since many bodybuilders begin preparing for a competition earlier than 6 weeks before, this information may be misleading. For example, 55% of the male and 75% of the female bodybuilders surveyed by Kleiner et al. (28) began restricting their diet between 2 and 4 months before competition. It is also possible that these women were chronically consuming a low energy diet in spite of high activity. We have previously reported that women involved in resistance training were more preoccupied with their weight, obsessed with food, and likely to use laxatives for weight control than women who did not do weight training (51).

Not surprisingly, bodybuilders tend to consume a relatively high protein diet during training (Table 1). Averages reported for both sexes are in the 19 to 26% range, with protein expressed as a percentage of kcal. The average range of protein intake for the bodybuilders in Table 1 expressed per kilogram of body weight, 1.7 to 2.8 g · kg^{-1}, is well above the RDA of 0.8 g

Table 1
Reported Dietary Energy and Macronutrient Intake During Noncompetitive Training Period

	BW (kg)	Energy (kcal)	Pro. (g)	% Pro.	% CHO	% Fat
Males						
Faber et al. (10)	81.6	3586	200	22	36	39
Heyward et al. (17)	91.5	3590	215	25	52	26
Tarnopolsky et al. (48)	80.0	4802	216	19	49	32
Females						
Heyward et al. (17)	58.3	1630	102	26	53	21

$\cdot$ kg^{-1} for this age group. However, averages sometimes obscure individuals with a low dietary intake. For example, Grandjean (13) found the average protein intake of a group of male weight lifters was 1.6 g $\cdot$ kg^{-1}. But the range of protein intake was from 0.8 to 2.5 g $\cdot$ kg^{-1}. Data we collected on female bodybuilders indicated that the average protein intake was well above the RDA during the 2 days prior to competition, at 1.3 g $\cdot$ kg^{-1} (53), but the range was from 0.7 to 1.9 g $\cdot$ kg^{-1}. So it cannot be assumed that all bodybuilders or weight lifters are consuming a high protein diet.

Fat intake during training appears to be moderate for most bodybuilders. The reports in Table 1 indicate that all averages were less than the 36% consumed by the average American except for the studies by Faber et al. (10). The high fat intake of 39% reported by Faber et al. may be secondary to the extremely high egg intake by some of the bodybuilders they studied, as many as 81 eggs a week. Given that their study was published in 1986, the practice may no longer be current. Recent studies have found that bodybuilders may consume high quantities of egg whites but rarely of whole egg (30).

Carbohydrate intake reported by the athletes in the studies listed in Table 1 was less than that recommended for endurance athletes (45). It was as low as 36% of kcal in the athletes studied by Faber et al. (10). None of the averages were greater than 53% of kcal from carbohydrate.

Precompetition Diet

Since bodybuilders are judged partly on muscle size and definition, their goal while preparing for competition is to reduce subcutaneous fat as much as possible while maintaining muscle mass. They achieve this partly by reducing energy intake. The men who have been studied while preparing for competition consumed about 50 to 60% as much energy as those who were not in the precompetition period (Table 2).

Energy intake for women while preparing for a contest varied in different groups studied and according to the length of time before competition. The lowest average intake, 891 kcal $\cdot$ d^{-1}, was reported by Lamar-Hildebrand et al. for women 3 weeks before competition (30). Table 2 lists the average energy and macronutrient intakes reported by various investigators for female bodybuilders within 1 week before their contests. The energy values ranged from approximately 1,300 to 2,300 kcal $\cdot$ d^{-1} (24.5 to 29.1 kcal $\cdot$ kg^{-1}).

Table 2
Reported Dietary Energy and Macronutrient Intake for Bodybuilders Preparing for Competition

Studies	BW (kg)	Energy (kcal)	Pro. (g)	% Pro.	% CHO	% Fat
Males						
Heyward et al. (17)[a]	86.1	2331	163	28	63	13
Kleiner et al. (27)[b]	80.0	2620	247	30	49	11
Kleiner et al. (28)[c]	80.1	2015	169	34	50	15
Sandoval et al. (44)[a]	82.2	2347	199	34	52	16
Females						
Heyward et al. (17)[a]	52.3	1453	77	21	72	10
Kleiner et al. (27)	53.0	1597	143	39	48	12
Kleiner et al. (28)[c]	57.4	2260	162	37	49	13
Lamar-Hildebrand et al. (30)[d]	55.6	1283	67	21	69	14
Sandoval et al. (44)[a]	52.5	1535	105	26	64	14
Walberg et al. (53)[a]	54.3	1839	72	17	78	6

Data obtained from: [a]2-day diet records for 2 days before competition; [b]3-day records for Days 8 to 10 before competition; [c]7-day diet records for 7 days before competition; [d]3-day diet records for 7 days before competition.

The two studies that followed female bodybuilders for 8 weeks before competition found that energy intake during this period resulted in weight reduction at an approximate rate of 0.7 kg per week (17, 30). Similarly, those women studied by our research group lost an average of 2.7 kg over the 4 weeks they were studied before their contests (53). Thus the average rate of weight loss was in the range recommended by nutritionists. However, a look at the individual bodybuilders reveals that some of them lost body weight at an inappropriate rate. For example, the weight loss of 6.4 kg over 4 weeks by one subject in our study (53) may have impaired her ability to complete her resistance training as well as affecting her health.

Data from our laboratory suggests that women involved in resistance training are more likely to have disturbances in menstrual function such as prolonged menstrual cycles and temporary cessation of menstruation (51). This adds to the numerous reports of menstrual irregularities in athletes involved in aerobic sports (34). The changes in menstrual cycle of the women involved in resistance training may be a result of the dietary restriction practiced by some of these women (53). We have shown an elevation in hormones known to disrupt the menstrual cycle in female resistance trainers who are in negative energy balance (54).

A very low energy intake may also lead to the loss of lean body mass. Heyward et al. (17) observed that 75% of the bodybuilders dieting prior to competition lost lean body mass. Those who lost the most lean tissue were those with the lowest energy intake. Thus rapid weight loss via severe dietary restriction should be discouraged for health and performance reasons.

Analysis of the macronutrient intake of bodybuilders preparing for competition shows that they tend to reduce fat intake dramatically. A study from our laboratory found that the reduction in dietary fat was progressive up until the day of the contest (53). The diet records from 4 weeks prior to the competition indicated an average of 17% fat while those during the 2 days before the contest had only an average of 6.4% dietary fat. This required strong discipline and restriction of various common foods.

The extremely low fat intake is one of the most unique characteristics of the diets of the bodybuilders who were preparing for a competition. It is important to put this dietary change into perspective. A diet that is 10% fat reflects a 72% reduction in the fat consumed by the typical American. There is no scientific justification to support this extreme diet, since weight loss is largely a function of magnitude of negative energy balance, not dietary fat. There is a misconception among bodybuilders that dietary fat has only one fate: storage as body fat. However, in a state of negative energy balance, the body utilizes dietary fat for energy.

A low fat diet may be helpful in reducing total energy consumption, since fat has more than twice the energy per unit weight as carbohydrate or protein. However, there is no evidence that a 10% fat diet is superior to an isocaloric 20% fat diet, for example, with regard to loss of body weight or fat. In fact there is evidence that the weight loss would be similar. Alford et al. (1) compared the weight loss of women on a 1,200 kcal · d^{-1} diet of either 10, 35, or 45% fat. There was no difference in the weight loss among groups over the 10-week study. Thus there is no empirical evidence that the extremely low fat diet consumed by many bodybuilders is necessary for losing body weight and fat. Further research could be conducted to study this issue.

In order to achieve a very low fat diet, the bodybuilders tend to consume repetitive diets containing few foods. Sandoval and Heyward (43) confirmed that food variety decreased between the noncompetition and precompetition diets of bodybuilders. For male bodybuilders, the average number of different foods dropped over 30% during preparation for competition. Data from our study showed that typical foods consumed during this time were chicken breast without skin, potatoes, rice cakes, and oatmeal. Lamar-Hildebrand et al. (30) found that foods frequently consumed by their athletes when preparing for competition included chicken, tuna, egg white, brown rice, rice cakes, and pasta. They specifically avoided egg yolks, red meats, and dairy products.

The only recent study that reported a high fat intake relative to that for other bodybuilders preparing for a contest was a case study by Manore et al. (35). The male athlete in that study consumed an average of 30% of his calories as fat during the 8 weeks before the contest. However, most of this was as medium chain triglyceride (MCT), which is metabolized differently from the long chain fatty acids typically found in foods. Excluding the MCT, his diet contained only 5% fat.

We have seen that the drop in dietary fat as the contest approached was partly balanced by an increase in carbohydrate intake in the female bodybuilders we studied (53). Diet records from Weeks 4 and 1 before competition indicated that just over half of their calories came from carbohydrate. However, the average dietary carbohydrate increased to 78% of calories during the 2 days before the competition. This is likely a reflection of carbohydrate loading during the week prior to competition. The athlete studied by Steen (46) attempted to complete a classical glycogen loading routine during the week before the contest, reasoning that the extra glycogen stored in muscles could help increase their size the day of the competition.

Other unusual patterns noted in dietary behavior of bodybuilders preparing for competition include an effort to eat frequently on a very rigid schedule. The subject studied by Steen (46) ate every 2 hrs, even setting an alarm to wake at night for eating.

The quality of the diets with regard to micronutrients typically deteriorated during the precompetition period, especially for female bodybuilders (17, 28, 30, 44, 53). The women studied by Lamar-Hildebrand et al. (30) had average B12, D, E, and folate intakes of less than 67% of the RDA during the precontest diet. Although none of the vitamin intakes examined as a group average fell below the recommended levels for the female bodybuilders we studied, there were more individuals with low vitamin intakes as contest time approached (53). The most common vitamins for which the individual intakes were less than 67% of the RDA were vitamins C, A, folate, and B12. Kleiner et al. (27) found that female bodybuilders consumed absolutely no vitamin D during Days 8 to 10 before their competition. Studies examining the diets of male bodybuilders typically did not find deficiencies of vitamin consumption (17, 44), possibly due to the higher caloric intake typical of these men relative to women. The exception was the low vitamin D intake, 46% of the RDA, reported of the male bodybuilders studied by Kleiner et al. (27).

Deficient mineral intake was more common than deficient vitamin intake during precompetition. Calcium intake of less than 67% of the RDA was reported in all the studies examining the precontest diet of female bodybuilders (3, 17, 27, 28, 30, 44, 53). Two studies also found deficient calcium intake for male bodybuilders preparing for competition (17, 44). Low zinc intake was observed in four of the studies examining the diets of female bodybuilders (3, 17, 30, 53). Only one study found that the average iron intake was less than 67% of the RDA (17).

Although no studies have actually measured fluid intake in bodybuilders, fluid restriction has been reported as a way to lose weight prior to competition. All bodybuilders surveyed by Kleiner et al. (28) said they restricted their fluid intake and practiced dehydrating procedures such as exercise in a sauna and wearing rubber suits. The subject studied by Steen (46) restricted his fluid intake to 2 cups of distilled water a day and down to only 1 cup a day during the week before the contest. Sodium was also limited in the diet to promote dehydration. The dangers of dehydration have been shown repeatedly, especially in wrestlers, who also are notorious for these practices (22).

A recent example of the potential consequences of dehydration was the death of Mohammed Benaziza, an internationally competitive professional bodybuilder. This 30-year-old athlete died of a heart attack shortly after winning the professional bodybuilding competition, Dutch Grand Prix. Those who competed with Benaziza claimed he had not consumed any fluids for 3 days prior to the competition (2). Dehydration through fluid restriction and diuretics should be strongly discouraged in these athletes.

Postcompetition

Few studies focus on specific changes in diet just after competition. One study that did include postcompetition data from a group of athletes was that by Lamar-Hildebrand et al. (30). However, they combined data from the day before, the day of, and the day after competition as one food record. Thus it is not possible to determine the changes in consumption after competition. Steen (46) reported in a case analysis of one bodybuilder that his energy consumption increased from an average of 1,936 kcal $\cdot$ d^{-1} for the 6 days preceding the competition to 5,360 kcal the day after the contest. The subject studied by Hickson et al. (19) consumed 1,571 kcal during the day prior to the evening competition. On the same day, after the contest, he consumed an additional 5,504 kcal.

In a group of 6 female bodybuilders, we found that energy intake almost doubled and fat consumption increased tenfold when food intake during the 2 days prior to competition was compared to the 3 days including and following competition (53). Protein intake remained high after competition at 2 g $\cdot$ kg^{-1}, but the contribution of this macronutrient to total energy intake fell to about 15%, compared to 34% of energy from protein 7 to 9 days before the contest. Carbohydrate dropped from 78% of energy intake during the 2 days before competition to a little over half of the total energy intake just after competition. Most of the deficiency in vitamin and mineral intake disappeared after the contest with the dramatic increase in variety and quantity of foods consumed.

II. Are Nutrient Needs Different?

Energy

Any type of activity increases energy needs. However, an activity such as resistance weight training which includes substantial rest time between lifting typically uses less energy per hour than aerobic exercise. Hickson et al. (20) studied the energy cost of weight lifting via indirect calorimetry in 4 men who weighed 70 to 97 kg. They found that the net energy cost was an average of 174 and 222 kcal per 36-min exercise session for upper body and lower body routines, respectively (290 and 370 kcal $\cdot$ hr^{-1}). This energy cost is remarkably similar to that reported by Meredith (37), 370 kcal $\cdot$ hr^{-1} for individuals who trained with weights 7 ± 1 hr $\cdot$ wk^{-1}. Kuehl et al. (26) developed equations to predict the energy cost of resistance training based on indirect calorimetry measurements of men and women. The total caloric expenditure for each lift was a function of total weight lifted. Thus, individuals who incorporate a high number of repetitions and sets in their resistance training sessions are likely to expend more calories than those who do higher intensity, lower volume workouts.

The high total energy requirements of bodybuilders in spite of a modest energy cost of resistance training is a function of the long duration and frequency of their resistance training workouts. The competitive bodybuilder studied by Hickson et al. (19) performed resistance training 6 days a week for 1 to 2 hrs. Female bodybuilders preparing for a competition were reported to do 13 hours a week of weight training.

Most bodybuilders also do aerobic exercise to reduce body fat. The bodybuilder described by Hickson et al. (19) did aerobic exercise 5 to 6 days a week for 45 to 60 min a session in addition to his resistance exercise routine. The 10.5 hrs of aerobic exercise performed by the female bodybuilders in Lamar-Hildebrand et al.'s study (30) would clearly have a significant impact on their total energy requirement. The most common aerobic activities of the female bodybuilders we studied during preparation for a competition were cycling and running (53).

Failure to consume adequate energy while weight training may have a dampening effect on strength and muscle mass gains. Studies have shown that consuming an energy supplement can increase the benefits of a weight lifting program (12, 15). Harberson (15) found that the addition of a 540-kcal supplement to self-selected diets in competitive male weight lifters over 15 weeks caused an increase in lean body mass equal to that of a group of weight lifters using anabolic steroids. The increase in strength and lean body mass was greater in the group getting the energy supplement than in the control subjects, who were also consuming self-selected diets. Gater et al. (12) found a similar benefit from a 360- to 540-kcal daily liquid supplement (60% carbohydrate, 15% protein, 25% fat) on lean body mass gain over 10 weeks in a group of novice bodybuilders when compared to subjects participating in the same resistance training who were not consuming the supplement. So, the most important nutritional factor for maximizing strength and lean body mass may simply be an increase in energy intake to allow for anabolism.

Protein

Many weight lifters and bodybuilders consume two to four times the RDA for protein. Is there scientific justification for an increase in protein requirement for these athletes? Urinary 3 methylhistidine (3MH) excretion is used as an index of muscle contractile protein catabolism. Although the initial short-term studies on the effect of weight lifting exercise on urinary nitrogen and 3MH excretion showed no effect (21, 23), the long-term studies indicate that chronic weight lifting increases 3MH excretion. For example, Pivarnik et al. (41) saw a significant increase in 3MH by Day 3 of resistance training in novice weight lifters that persisted for the remaining measurement period. Thus resistance training appears to increase the breakdown of contractile muscle protein.

In order to maintain muscle mass, the increased muscle breakdown must be countered by an increase in muscle protein anabolism following the exercise. Chesley et al. (7) showed an increase in muscle protein synthesis in 6 male subjects within 4 hrs after a single resistance exercise bout. This was confirmed by measuring the incorporation of labeled leucine into muscle biopsy samples. Muscle hypertrophy would obviously require an increase in muscle protein synthesis greater than the increase in degradation.

Several investigators have attempted to determine the protein intake that will result in nitrogen balance. Some have found that no increase in protein intake was required for nitrogen balance. Meredith et al. (38) evaluated 7 experienced male weight trainers in a metabolic ward for three 10-day periods at three protein intakes (0.56, 0.84, 1.15 $g \cdot kg^{-1}$) and found that even the lowest protein intake resulted in a positive nitrogen balance. The protein requirement was calculated to be only 0.52 $g \cdot kg^{-1} \cdot d^{-1}$, which is similar to that observed for sedentary men. Although this value is below the RDA, note that the RDA for protein is derived by first determining the average protein requirement to achieve nitrogen balance. Then this value is increased by 30% to account for individual variability and is further increased by 30% to allow for consumption of proteins of differing quality and digestibility (39). Thus any study determining the protein intake required for nitrogen balance in these athletes must be modified upward to account for the above factors.

Other researchers suggest an increase in protein requirement for resistance trainers. A recent report on protein requirements in strength training athletes used not only the nitrogen balance technique but also labeled leucine infusion studies to compute whole-body protein synthesis and breakdown (47). A group of experienced strength trained athletes was compared to a group of age-matched sedentary controls. Both groups were tested at three protein intake levels: low, moderate, and high (0.86, 1.4, and 2.4 $g \cdot kg^{-1}$, respectively). Results showed that although the sedentary subjects were in positive nitrogen balance at the lowest protein intake, most of the strength trained athletes were in negative nitrogen balance on this diet. Calculation of protein intake required for zero balance was 1.4 $g \cdot kg^{-1}$ for strength athletes and 0.69 for sedentary subjects. An increase in protein intake from low to moderate increased the rate of protein synthesis in strength athletes, as measured by labeled leucine, but a further increase did not accelerate protein synthesis. Thus the researchers concluded that the moderate protein diet at 1.4 $g \cdot kg^{-1}$ would allow for positive nitrogen balance and be at the peak value for stimulating body protein synthesis.

Lemon (33) also concludes from work in his laboratory and others that strength training athletes should consume more protein than the RDA. He recommends that athletes doing resistance training consume 1.5 to 2.0 $g \cdot kg^{-1} \cdot d^{-1}$. Lemon points out that this recommendation is valid only if energy needs are met. All the studies mentioned above that analyzed nitrogen needs were looking at athletes in energy balance.

Our laboratory has looked at protein needs during energy restriction, since bodybuilders preparing for competition may restrict energy intake for up to 3 months prior to the event. The recreational male resistance trainers we studied were in negative nitrogen balance for 7 days while consuming 18 $kcal \cdot kg^{-1}$ and the RDA of 0.8 $g \cdot kg^{-1}$ protein per day (52). Another group who consumed protein at twice this level but at the same restricted energy intake had a positive balance during this time period.

A more recent study from our lab found that a diet of 1.2 $g \cdot kg^{-1}$ protein and energy restriction at 22.8 $kcal \cdot kg^{-1}$ in male resistance weight trainers over 10 days maintained nitrogen balance even though average body weight decreased about 3.2 kg (55). This suggests that the protein requirement for this population during weight loss is from 0.8 to 1.2 $g \cdot kg^{-1} \cdot d^{-1}$. Since the RDA for protein is set by adding 30% for individual variability and another 30% for differences in protein quality to the average protein required for nitrogen balance, as noted earlier, the actual protein recommended for this population during weight loss would be as high as 2.0 $g \cdot kg^{-1} \cdot d^{-1}$ when preparing for bodybuilding competitions.

Butterfield et al. (6) examined the condition of positive energy balance in male resistance trainers. The energy and protein requirements for maintaining weight and nitrogen balance in the athletes were determined in a metabolic ward. All athletes were given a 400-$kcal \cdot d^{-1}$ supplement as either fat and carbohydrate or as protein with fat and carbohydrate. The protein intake of the latter group was 1.5 times the calculated requirement, or approximately 1.17 $g \cdot kg^{-1} \cdot d^{-1}$. The athletes were fed these diets for 2 weeks while continuing their resistance training. During the 2nd week both groups were found to be in positive nitrogen balance. There was no significant difference between the nitrogen balance of the dietary groups, but the protein supplemented group tended to have a higher balance (1.43 vs. 1.29 g nitrogen per day). It is not known whether, given more time, the protein supplemented group would have had higher nitrogen retention and possibly a gain in lean tissue.

Few long-term studies have been published on dietary protein manipulation in bodybuilders. This is not surprising, considering the tight control of diet and activity and the inconvenience of the excretory collections that are required to do nitrogen balance studies. Hickson and Hinkelmann (18) reported no strength gain from a diet containing three times the RDA versus one having the RDA for protein in a group of men participating in a resistance weight program for 28 days. Since they measured urinary nitrogen but not fecal or sweat nitrogen, nitrogen balance could not be determined (36).

Thus there are short-term studies (<2 weeks) of protein requirements in bodybuilders but they are not in agreement. The evidence suggests it is prudent for the resistance trainer to consume at least 1.2 but not more than 2 $g \cdot kg^{-1} \cdot d^{-1}$ protein. Very high protein intake should be discouraged because of possible increases in urinary calcium loss (16); it may also lead to high cholesterol and saturated fat intake if the protein source is red meat or whole eggs, and it may displace carbohydrate in the diet (29). Since many bodybuilders appear to be consuming above the RDA for protein, they will probably not need to change their diet.

The above studies on the protein intake of bodybuilders typically considered only the protein provided by foods. Yet any magazine for bodybuilders will reveal a wide assortment of protein and amino acid supplements marketed to this population. Katch et al. (25) reported that of 39 weight lifters and bodybuilders, 23 of them consumed a protein supplement. An evaluation of the various supplements for bodybuilders found that amino acid mixtures were the largest category targeted for this population (14). Thus many bodybuilders are likely to be using protein and/or amino acid supplements.

The supplements used are often one or two specific amino acids such as arginine, ornithine, or lysine. They are touted as "natural steroids" that will increase endogenous production of anabolic hormones (14). The manufacturers suggest that these hormones will increase muscle growth while stimulating the breakdown of body fat. These claims are based on the clinical literature which documents that several amino acids are powerful simulators of insulin and growth hormone (GH) release when given intravenously. In fact normal function of the pituitary is sometimes clinically tested by injecting arginine and watching for the normal increase in GH that should follow. Since GH is known to stimulate protein synthesis, amino acids have been administered intravenously to reduce body protein loss in trauma, surgical, and burn patients. So the ability of some amino acids to increase GH and possibly influence body protein when given intravenously is well accepted. The controversy centers around the oral consumption of amino acids.

Some studies have found an increase in GH with arginine or ornithine supplementation while others have not. Isadori et al. (24) reported a sevenfold increase in growth hormone 90 min after oral consumption of 1,200 mg of arginine and lysine combined. However, it is unclear why a higher dose of arginine alone had no effect since arginine is the most potent stimulator of growth hormone when given intravenously. Besset et al. (4) did not observe an acute increase in GH in men consuming arginine twice a day but did find that nocturnal GH was higher in men taking the supplement. Bucci et al. (5) observed a significant increase in blood GH in a group of female and male bodybuilders consuming 170 $mg \cdot kg^{-1}$ (12 g for a 70-kg individual) of ornithine. However, this dose also resulted in mild to severe gastrointestinal distress in all subjects. This suggests that the use of ornithine is not practical. It is curious that both sexes were used in their study, since growth hormone levels are higher in women than in men, thus any response to these amino acid supplements may differ between the sexes.

Elam (8) and Elam et al. (9) used an oral arginine/ornithine supplement in untrained men over a 5-week period of strength training. The first study reported a greater reduction in body weight and body fat in those using amino acid supplements than in those taking a placebo. However, a reduction in body weight is not typical for persons of normal weight beginning a weight lifting program. Elam et al. claimed that the reduction in body fat was secondary to an increase in GH. However, GH was not measured. The second study also concluded that the supplement enhanced strength gain over a 5-week training program relative to the placebo. However, strength was only assessed after the resistance training program, thus initial differences in strength between groups cannot be discounted.

Gater et al. (12) did measure strength before and after a controlled resistance training program. They did not find a benefit from a daily arginine/lysine supplement of 0.066 g amino acid per kg fat-free mass on strength gain over a 10-week period in novice male weight trainers. In addition, the lack of change in total plasma IGF-1 suggests there was no increase in GH in these athletes over the period.

Two recent studies examining the effect of short-term ingestion of amino acid supplements of arginine/lysine, ornithine/tyrosine, or arginine/lysine/ornithine combinations did not observe an increase in GH in resistance trained athletes. Lambert et al. (32) examined the acute effect over a 3-hr period in bodybuilders after ingesting the supplements, while Fogelholm et al. (11) looked at the 24-hr GH response following 4 days of arginine/ornithine/lysine supplement ingestion in competitive weight lifters.

A study completed in our laboratory examined the potential effects of oral arginine supplementation on GH, body composition, and muscle function in experienced male resistance trainers undergoing weight loss (55). This was of interest since some of the clinical tests of oral arginine consumption on lean body mass have been conducted on patients in a catabolic state such as postsurgery. We found no acute effect of arginine (0.1 g $\cdot$ kg^{-1}) on GH or blood arginine. Muscle strength was reduced in both groups as a result of energy restriction for 10 days, but there was no effect of the supplement on this parameter. Nitrogen balance was not affected by the arginine supplements. In summary, we were not able to detect any positive effects of oral arginine supplementation.

It is important to note that many of these studies employed doses of arginine and ornithine well in excess of the doses recommended by manufacturers. For example, our study administered arginine at 0.1 g $\cdot$ kg^{-1} twice a day whereas manufacturers often recommend 1 to 2 g $\cdot$ d^{-1} (0.01 to 0.02 g $\cdot$ kg^{-1} for an 80-kg individual). The benefits of arginine and ornithine supplementation reported by some investigators need to be repeated in other laboratories in order to be convincing. At this point there does not appear to be good scientific evidence for an effect of oral arginine or ornithine on body composition or muscle strength.

Carbohydrate

The primary fuels used to regenerate ATP during weight lifting are creatine phosphate and glucose/glycogen. Tesch et al. (49) have reported a reduction in muscle glycogen of 26% after resistance weight training. Thus the carbohydrate needs of a person training with weights may be higher than for a sedentary person. Rinehardt (42) studied whether a high carbohydrate diet would actually facilitate ideal total body weight, lean mass, and strength gain than a diet of the same energy value but lower in carbohydrate. The novice male weight trainers gained similar amounts of weight and lean body mass over the 9-week training program whether they consumed a diet of 40% or 65% carbohydrate. Nitrogen balance was positive for both groups throughout the study but was not affected by diet. Strength gains in the bench and leg press were the same regardless of the diet consumed.

Van Zant et al. (50) also report that a diet of 62% carbohydrate had no benefit over a diet of 42% carbohydrate over 3 weeks with regard to muscle strength or endurance. Thus the research so far does not find that a high carbohydrate training diet is advantageous for body composition or muscle performance changes during training.

We did find an effect of carbohydrate/protein ratio of the diet on muscle endurance during a weight loss period in bodybuilders (52). A lower carbohydrate diet (50% of calories) depressed muscle endurance more than a higher carbohydrate diet of 70% carbohydrate in resistance weight trainers who lost an average of 3.6 kg and 4.0 kg over 7 days, respectively. This difference, observed during weight loss, was not observed by others during energy balance and may relate to the additional drain on carbohydrate stores during energy restriction.

Carbohydrate supplements prior to and during aerobic exercise have been shown to enhance performance. Since muscle glycogen is not found to be totally depleted during a typical weight lifting bout (43), the value of a carbohydrate supplement has been discounted. However, Lambert et al. (31) have shown that consumption of a glucose polymer solution before and during a weight lifting session tended (p = 0.067) to increase the number of leg extension sets that could be performed at 80% 1-RM (17.1 vs. 14.4 sets for glucose polymer and placebo, respectively). This suggests that carbohydrate supplementation may help delay fatigue for those involved in resistance weight training. These supplements are unlikely to have any effect on maximal strength, however, and thus would not aid a power lifter during competition but may enhance the quality of training workouts. This may be especially true during periods of energy restriction and weight loss.

Pascoe et al. (40) showed that consumption of a carbohydrate solution after a resistance training workout can enhance the rate of muscle glycogen repletion. Muscle glycogen fell approximately 30% during a repetitive leg extension test. Carbohydrate stores were replenished to 91% of initial values 6 hrs after the exercise when the subjects consumed a 23% carbohydrate solution immediately after and 1 hr after the workout, as compared to only 75% replenishment with ingestion of water. Thus, athletes who perform exercise workouts or compete several times a day can recover more rapidly if they consume carbohydrate after their activity. The study did not determine the value of solid as compared to liquid feedings, or the optimal amount of carbohydrate that should be consumed.

Practical Application

There is only a modest amount of research on the dietary practices and requirements of bodybuilders. Thus these recommendations are based on a limited number of studies and may require revision as more research is done with these athletes.

For a bodybuilder who would like to increase his or her lean body mass, the most important nutritional factor is adequate energy intake to allow for anabolism. This can be achieved by increasing the quantity of the usual diet or by adding a liquid meal supplement to diet. Protein requirement for growth of lean tissue is likely to be greater than that for maintenance, possibly in the range of 1.2 to 2.0 g · kg^{-1}. However, the typical diet of most bodybuilders already includes that amount of protein. Recent research suggests that carbohydrate supplements may be useful before, during, and after a resistance training session to maximize muscle performance and recovery. More research is needed in this area.

The low fat diets consumed by many bodybuilders when preparing for competition may be unnecessarily extreme, since the great reduction in food choices increases the chance of inadequate micronutrient intake. A goal of 15 to 20% fat, rather than the average of 6% dietary fat we observed in female bodybuilders, would be achievable without an extremely rigid diet. Overzealous restriction of energy intake is detrimental in that it reduces lean body mass in bodybuilders. A moderate reduction in usual energy intake by 500 to 1,000 kcal a day would be ideal for minimizing the loss of lean tissue. This would translate into approximately 2,500 to 3,000 kcal · d^{-1} for male bodybuilders and 1,200 to 1,700 kcal · d^{-1} for female bodybuilders. Individual values would vary depending on resting metabolic rate (influenced by body weight and composition) and activity level.

Most of the calories in the diet should come from carbohydrates (up to 60%) in order to protect carbohydrate stores and muscle function. This may require a change in food choices or a carbohydrate supplement for bodybuilders, since the intakes observed during training were approximately half of calories from carbohydrate. Protein requirements while consuming an energy restricted diet are higher than those during maintenance energy intake, thus would likely be at the upper end of the 1.2 to 2.0 g · kg^{-1} range suggested earlier.

There is no evidence for an increase in requirement for micronutrients. However, low intake of some (especially vitamins C, A, folate, and B12, and minerals calcium and zinc) micronutrients is reported in some bodybuilders. These low nutrient intakes could be relieved by increased consumption of low fat dairy products, fruits, vegetables, and lean meats. If the bodybuilder is unwilling to alter his or her diet, a multiple vitamin/mineral complex at the RDA level may be appropriate. Sodium and fluid restriction should be discouraged because this leads to dehydration, which in turn has a detrimental effect on performance and health. The bulk of the scientific evidence shows that the amino acid supplements arginine, ornithine, and lysine do not affect hormonal status, muscle size, or muscle function.

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