REVIEW ARTICLE

Sports Med 2004; 34 (5): 317-327
0112-1642/04/0005-0317/$31.00/0

Macronutrient Considerations for the Sport of Bodybuilding

Charles P. Lambert,[1] *Laura L. Frank*[2] and *William J. Evans*[1]

1 Nutrition, Metabolism, and Exercise Laboratory, Donald W. Reynolds Center on Aging, Department of Geriatrics, University of Arkansas for Medical Sciences and Geriatric Research, Education and Clinical Center, Central Arkansas Veterans Healthcare System, Little Rock, Arkansas, USA

2 Department of Psychiatry and Behavioral Sciences, University of Washington School of Medicine and Geriatric Research, Education and Clinical Center, Puget Sound Health Care System, Seattle, Washington, USA

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Abstract

Participants in the sport of bodybuilding are judged by appearance rather than performance. In this respect, increased muscle size and definition are critical elements of success. The purpose of this review is to evaluate the literature and provide recommendations regarding macronutrient intake during both ‘off-season’ and ‘pre-contest’ phases. Body builders attempt to increase muscle mass during the off-season (no competitive events), which may be the great majority of the year. During the off-season, it is advantageous for the bodybuilder to be in positive energy balance so that extra energy is available for muscle anabolism. Additionally, during the off-season, adequate protein must be available to provide amino acids for protein synthesis. For 6–12 weeks prior to competition, body builders attempt to retain muscle mass and reduce body fat to very low levels. During the pre-contest phase, the bodybuilder should be in negative energy balance so that body fat can be oxidised. Furthermore, during the pre-contest phase, protein intake must be adequate to maintain muscle mass. There is evidence that a relatively high protein intake (~30% of energy intake) will reduce lean mass loss relative to a lower protein intake (~15% of energy intake) during energy restriction. The higher protein intake will also provide a relatively large thermic effect that may aid in reducing body fat. In both the off-season and pre-contest phases, adequate dietary carbohydrate should be ingested (55–60% of total energy intake) so that training intensity can be maintained. Excess dietary saturated fat can exacerbate coronary artery disease; however, low-fat diets result in a reduction in circulating testosterone. Thus, we suggest dietary fats comprise 15–20% of the body builders' off-season and pre-contest diets.

Consumption of protein/amino acids and carbohydrate immediately before and after training sessions may augment protein synthesis, muscle glycogen resynthesis and reduce protein degradation. The optimal rate of carbohydrate ingested immediately after a training session should be 1.2 g/kg/hour at 30-minute intervals for 4 hours and the carbohydrate should be of high glycaemic index. In summary, the composition of diets for body builders should be 55–60% carbohydrate, 25–30% protein and 15–20% of fat, for both the off-season and pre-contest phases. During the off-season the diet should be slightly hyperenergetic (~15% increase in energy intake) and during the pre-contest phase the diet should be hypoenergetic (~15% decrease in energy intake).

The major goals of competitive body builders are to increase muscle mass in the 'off-season' (no competition) and to reduce body fat to very low levels while retaining muscle mass during the 'pre-contest' period. The resistance training workouts during these two phases, in general, should be similar regarding the number of sets and repetitions, and the bodybuilder should attempt to maintain the amount of resistance he/she trains with during the pre-contest phase. The notion that one should perform a high number of sets and repetitions with little rest between sets to 'burn fat' during the pre-contest phase is without basis due to the low energy expenditure associated with resistance training,[1] and may result in a loss of muscle mass due to the use of low exercise intensities associated with short rest periods between sets[2] and the high number of repetitions. It is our belief that aerobic exercise and energy restriction should be used to reduce body fat rather than high-repetition, high-set, brief rest-period resistance training.

The major goal during the off-season is muscle mass accretion; adequate energy intake is required so that the bodybuilder can be in positive energy balance (i.e. be taking in slightly more energy than that required for weight maintenance). This will ensure that weight gain will occur and combined with high-intensity resistance training will promote muscle mass accretion.[3] Also, adequate protein intake is required and the timing of the protein/amino acid intake appears to be important for the accretion of muscle mass (as discussed in section 3). Adequate carbohydrate stores are essential to fuel high-intensity resistance training. The timing, amount and type of carbohydrate have a bearing on muscle glycogen synthesis (as discussed in section 4). The purpose of this review is to evaluate the literature and provide recommendations for dietary macronutrient composition and total energy intake, and the timing, amount and composition of pre- and post-exercise nutrition for body builders during off-season and pre-contest phases.

1. Macronutrient Composition for Optimal Muscle Mass Accretion

1.1 Protein

Muscle is primarily protein and water. In order to maintain muscle mass, adequate dietary protein intake is required. The rates of muscle protein degradation and synthesis increase in response to high-intensity resistance exercise, with a greater increase in the rate of synthesis.[4] With regard to the time period of the increase in skeletal muscle protein synthesis, Chesley et al.[5] reported that muscle protein synthesis was elevated by 50% at 4 hours and 109% at 24 hours as a result of 12 biceps resistance exercise sets of 6–12 repetitions at 80% of 1 repetition maximum, each of which were taken to the point of muscular failure. Because of this response, an increased amount of dietary protein is utilised for muscle growth compared with pre-exercise levels. This suggests that at any dietary protein intake, nitrogen balance (an indication of whole body protein use) is improved by strength training, thus decreasing the dietary protein requirement (as discussed by Rennie and Tipton[6]). There are data suggesting that the levels of protein intake of 1.2[7]–1.7[8] g/kg/day are required for body builders. This is substantially greater than the level of protein intake of 0.8 g/kg/day suggested for the general population; but as reviewed by Rennie and Tipton,[6] these studies may be flawed methodologically. In these studies, it is unclear whether the individuals were in energy balance, whether they were at a steady level of training and/or whether the exercise intensity in the experiments matched their habitual training intensity.[6]

Furthermore, Campbell et al.[9] reported that in elderly individuals who initiated a resistance training programme for 12 weeks, 1.6g of protein/kg/day was no more effective in promoting a positive nitrogen balance than 0.8g of protein/kg/day. Thus, from the available data it appears that the protein requirements to promote anabolism for individuals engaged in resistance training are similar to individuals who do not resistance train due to the increased efficiency of amino acid utilisation. However, because of the large thermic effect of protein, we suggest that the protein intake should be 25–30% of total energy intake which under most, if not all circumstances, will be >0.8g of protein/kg/day. A 25% protein diet would allow for adequate carbohydrate intake to provide energy during resistance-training sessions and adequate fat to maintain circulating testosterone levels as discussed in section 1.2 and section 1.3.

Anabolic steroids and testosterone administration clearly increase muscle mass.[10-13] The available evidence suggests that the use of testosterone or anabolic steroids reduces the amount of protein required for nitrogen balance.[14,15] This is likely due to an increase in the reutilisation of amino acids from protein breakdown for protein synthesis resulting from androgen administration.[16] Thus, the amount of protein required for muscle mass accrual may be less for individuals on testosterone or anabolic steroids than for individuals who do not use them. We do not promote the use of anabolic steroids because of their potentially adverse effects and because they are illegal; however, it is clear many body builders choose to use them.

1.2 Carbohydrate

The optimal carbohydrate intake for body builders has not been clearly defined; however, the available research does provide adequate information for the formulation of guidelines. Glycogen is the major substrate for high-intensity exercise including moderate-repetition (8–12 repetitions) resistance exercise.[17] MacDougall et al.[17] reported that glycolysis provided the great majority of adenosine triphosphate (ATP) [~82% of ATP demands] during one set of biceps curls taken to the point of muscular failure. Twelve repetitions were performed and the exercise duration was 37 seconds. At this exercise intensity, it can be assumed that almost all of the fuel for muscle contraction was provided by muscle glycogen.[18] Because of the great dependence of bodybuilding workouts on muscle glycogen, it follows that low muscle-glycogen levels would impair high-intensity exercise performance including resistance-exercise performance. This is supported by most[19-23] but not all available literature.[24]

MacDougall et al.[25] had individuals perform 6–17 1-minute bouts on a cycle ergometer at 140% of maximum oxygen consumption. Muscle glycogen was reduced by 72%. These investigators found that the consumption of 3.15g of carbohydrate/kg of bodyweight restored muscle glycogen to a pre-exercise level 24 hours post-exercise. No added benefit was gained by the ingestion of 7.71g of carbohydrate/kg of bodyweight. However, the exercise performed in the study of MacDougall et al.[25] differs from resistance training as there was no eccentric component. Gibala et al.[26] reported that eccentric muscle contractions induce muscle damage even in highly trained body builders. It has been previously demonstrated that muscle damage resulting from eccentric exercise results in greatly reduced capacity for glycogen storage[27] due to decreased insulin-stimulated glucose transport into muscle cells.[28-30] Costill et al.[31] reported that muscle damage may increase the dietary carbohydrate requirement for optimal muscle glycogen resynthesis. Based on these data, we suggest that body builders ingest 5–6g of carbohydrate/kg/day for optimal muscle-glycogen levels or that carbohydrate should comprise 55–60% of daily energy intake.

1.3 Fat

Clearly much less is known about the role of dietary fat on influencing exercise capacity, muscle mass accretion and losses of body fat when compared with what is known about protein and carbohydrate. A high-fat diet appears to impair high-intensity exercise capacity relative to a high-carbohydrate diet.[32-34] Little is known about the effects of fat content of the diet on muscle mass accretion. There is evidence, however, that both lowering the fat content of the diet and replacing saturated fat with polyunsaturated fat can reduce circulating testosterone levels.[35] Hamalainen et al.[35,36] reported that reducing dietary fat from 40% of energy intake to <25% of energy intake and drastically increasing the polyunsaturated to saturated fat ratio intake in healthy male volunteers resulted in a 15% decline in the total testosterone level. Dorgan et al.[37] reported that a low fat (18% of energy intake) and high polyunsaturated fat intake resulted in a 13% lower total testosterone level than when a diet with a high fat (41% of energy intake) and low polyunsaturated to saturated fat intake was ingested.

Berrino et al.[38] reported that when a diet low in animal fat and refined carbohydrates and high in low-glycaemic-index foods, with high monounsaturated fats, high n-3 polyunsaturated fats and high phytoestrogens replaced a typical high-fat western diet there was a 20% decline in the total testosterone level in postmenopausal women. Thus, it appears that reducing total fat intake and drastically increasing the polyunsaturated to saturated fat ratio results in a decrease in total testosterone. Whether this decrease in total testosterone influences muscle mass has yet to be established. This potential negative effect of reducing dietary saturated fat and increasing polyunsaturated fatty acids on the testosterone level must be balanced with the potential beneficial effects of these changes on cardiovascular risk factors. Clearly more research on these relationships needs to be conducted. Because high dietary fat greatly increases energy intake and has a negative impact on the cardiovascular system and because it is possible that drastically reduced fat can result in a reduction in circulating testosterone levels we suggest that the off-season bodybuilding diet has a moderate level of fat; ~15–20% of total energy intake with some saturated fat. This recommendation must be considered in light of the positive benefits of a relatively high-carbohydrate diet (55–60% of total energy intake) on high-intensity exercise performance and the benefits of additional protein (25% of energy intake) for muscle mass accretion and for its very high thermic effect.

2. Efficacy of a Positive Energy Balance on Resistance Exercise-Induced Gains in Muscle Mass

Protein synthesis is an ATP-dependent process. Because of this, muscle protein synthesis might be augmented during periods of positive energy balance, and diminished during negative energy balance. A significant gain in fat-free mass with overfeeding is also supported in the literature.[39] Thus, in untrained individuals, providing extra energy intake without any other anabolic stimuli results in accumulation of fat-free mass in addition to fat mass. There are data available suggesting that by increasing energy intake above that needed for weight maintenance during resistance training, muscle mass gains may be augmented.[3] Meredith et al.[3] provided elderly men (aged 61–72 years) with 560 extra kcals and ~24 extra grams of protein and had these individuals resistance train. These individuals were then compared with individuals who resistance trained on their normal diet. The investigators reported that those individuals receiving the energy/protein supplement had a significantly greater increase in thigh muscle mass than individuals who resistance trained but did not ingest the supplement. In addition, the change in energy intake was correlated with the change in the mid-thigh muscle area ($r = 0.69$; $p = 0.019$). However, it is unclear from the experimental design whether the greater increase in the mid-thigh muscle area in those individuals receiving the supplement and resistance training was due to increase in energy intake and/or protein intake. The intake of extra energy and extra protein in combination is common practice for body builders during the off-season. Thus, the data from Meredith et al.[3] would suggest that the intake of a protein/energy supplement may be efficacious.

3. Timing of Amino Acid/Protein Intake Following Resistance Exercise

Net positive protein balance means the muscle is in an anabolic state (i.e. protein synthesis is greater than protein breakdown) while net negative protein balance is an indication that the muscle is in a catabolic state (i.e. protein synthesis is less than protein breakdown). While an individual is fasting, net protein balance for muscle is negative.[40] An acute resistance exercise session increases protein synthesis to a greater degree than it increases protein breakdown; however, net protein balance remains negative.[40] An infusion of amino acids while individuals were in the fasted, nonexercised condition, increased muscle protein synthesis which resulted in a slightly positive net protein balance.[41] Following a single bout of resistance exercise, an amino acid infusion increased net protein balance to a significantly more positive value than amino acid infusion alone.[41] Similar increases were observed with the ingestion of essential amino acids after exercise.[42] The amount of amino acids required for this change to take place is small (6g of essential amino acids) and an added benefit was achieved with the ingestion of 35g of sucrose.[43] Muscle net protein balance is similar when the amino acid solution is ingested at 1 or 3 hours after the resistance exercise session.[44] More recent research suggested that when the amino acid solution was ingested immediately before a resistance exercise session, net protein balance increased to a significantly greater extent than ingesting the solution after the resistance exercise, possibly due to greater muscle blood flow and amino acid delivery.[45]

With regard to amino acid supplementation combined with a resistance training programme versus the effects of amino acids on an acute resistance exercise bout, Esmarck et al.[46] reported that the supplementation of 10g of protein, 7g of carbohydrate and 3g of fat immediately after each resistance training bout increased muscle mass; however, when this same supplement was ingested 2 hours after each resistance exercise bout in a separate group of individuals, no increase in muscle mass was observed. The men in that study were on average 74 years of age and they trained for 12 weeks. Godard et al.[47] reported, however, that the ingestion of 12g of essential amino acids combined with 72g of sucrose immediately after each resistance exercise bout resulted in no greater muscle hypertrophy or increase in strength than the resistance training without supplementation. The training period for that study was 12 weeks and the average age of the individuals was 71.5 years. Thus, although acute amino acid ingestion increases protein synthesis it is uncertain whether this results in muscle mass gains over the long term. However, it is our recommendation that individuals who engage in resistance exercise should ingest amino acids/protein prior to or immediately after the end of their training sessions, as this may enhance long-term muscle hypertrophy. It is unclear at present what the optimal form of protein is for maximal enhancement of net protein balance.

Miller et al.[43] administered 6g of amino acids, 35g of carbohydrate or the combination of the two at 1 and 2 hours after resistance exercise to examine the independent and combined effects of carbohydrates, amino acids and exercise with regard to net phenylalanine uptake by muscle (a measure of anabolism). They found that carbohydrate and amino acids and the combination of the two all significantly increased net phenylalanine uptake and that the combined effects of amino acids and carbohydrate were additive: 53, 71, 114 mg/leg/3h for carbohydrate, amino acids, and the mixture of the two, respectively. Furthermore, these investigators reported that there was a reduction in the rate of urea production and the rate of phenylalanine appearance from muscle into blood in the carbohydrate group relative to the resting value, suggesting reduced muscle proteolysis.

Roy et al.[48] reported that the ingestion of 1 g/kg of glucose immediately and 1 hour after a resistance exercise bout resulted in a significant 8% reduction in urinary 3-methylhistidine excretion in the carbohydrate versus placebo group, and a significant 30% reduction in urea nitrogen excretion when comparing carbohydrate to placebo groups was also observed. In a subsequent study,[49] these investigators compared administering 1 g/kg of glucose to providing the same amount of energy with a different macronutrient composition: carbohydrate (66%), protein (23%) and fat (~12%). These investigators found that nonoxidative leucine disposal (an indicator of whole body protein synthesis) was ~41% and ~33% greater for carbohydrate/protein/fat and carbohydrate conditions compared with the placebo condition. However, whole body protein synthesis may or may not be representative of the anabolic/catabolic processes occurring directly in skeletal muscle. Recently, Borsheim et al.[50] reported that the ingestion of 100g of carbohydrate after a resistance training session resulted in an improvement in phenylalanine net balance via a reduction in proteolysis; however, phenylalanine net balance did not reach positive values. The ingestion of essential amino acids after resistance training results in values substantially above zero for net phenylalanine balance.[42] These findings suggest a relatively minor effect of carbohydrate ingestion on muscle protein metabolism post-exercise. In summary, providing amino acids and carbohydrate immediately prior to resistance exercise and/or immediately after the exercise appear important for inducing a positive net protein balance and muscle anabolism. This increase in muscle protein balance may result from increased sensitivity of muscle cells to insulin as a result of contraction,[51] increased blood flow and therefore amino acid delivery to muscle cells that is both caused by exercise[45] and insulin[52] or a combination of both factors. However, whether or not these practices lead to greater muscle hypertrophy in the long term has yet to be established.

4. Optimal Post-Exercise Nutrition to Maximise the Rate of Muscle Glycogen Repletion

Ivy et al.[53] reported that the rate of muscle glycogen resynthesis over 4 hours was 76% greater when carbohydrate was provided immediately after exercise compared with 2 hours after exercise. This accelerated rate of glycogen resynthesis is likely due to the insulin-like effect of exercise on skeletal muscle glucose uptake.[54] Ivy et al.[55] also investigated the effect of the amount of carbohydrate ingested on the rate of glycogen resynthesis. They observed that the ingestion of 1.5g of carbohydrate/kg of bodyweight immediately after and 2 hours after exercise (rate of 0.8 g/kg/hour) resulted in a similar muscle glycogen resynthesis rate 4 hours after ingestion, as the ingestion of 3.0g of carbohydrate/kg of bodyweight (rate of 1.5 g/kg/hour) at these same time points. However, more recent data where carbohydrate solutions were ingested every 30 minutes suggest that the ingestion of 1.2g carbohydrate/kg/hour is significantly better at increasing the rate of glycogen synthesis than ingestion at a rate of 0.8 g/kg/hour.

With regard to the impact of the type of carbohydrate on the rate of muscle glycogen resynthesis, Burke et al.[56] reported that the ingestion of high-glycaemic-index carbohydrates resulted in a significant 48% greater rate of muscle glycogen resynthesis than the ingestion of low-glycaemic-index carbohydrates 24 hours after ingestion. Thus, it appears that high-glycaemic-index carbohydrates should be ingested in the first few hours after exercise. Recently, Ivy et al.[57] investigated the effects of the addition of protein to carbohydrate on the rate of muscle glycogen resynthesis. These investigators reported that the addition of 28g of protein to 80g of carbohydrate and 6g of fat, given 10 minutes post-exercise and 2 hours post-exercise, resulted in a 27% greater rate of muscle glycogen accumulation over 4 hours than the ingestion of 80g of carbohydrate and 6g of fat without protein. However, more recently, van Loon et al.[58] reported that additional carbohydrate added to a carbohydrate solution was just as effective as additional protein or amino acids added to a carbohydrate solution with respect to the rate of muscle glycogen synthesis. Based on these studies it is recommended that 1.2g of carbohydrate/kg/hour be ingested at 30-minute intervals for 4 hours after exercise. The carbohydrate ingested should have a high-glycaemic index[56] (i.e. result in a rapid increase in blood glucose levels). These recommendations will help to maximise the rate of muscle glycogen resynthesis after exercise. The question that has not been answered by most of these studies is: do the dietary practices studied over a very short period of time (~4 hours in most studies[53,55,57,58]) have an impact on muscle glycogen levels 24–48 hours after exercise of a given muscle group?

5. Optimal Macronutrient Composition for Fat Loss and Muscle Mass Maintenance

Typically, the pre-contest phase lasts between 6–12 weeks. The body composition goals of body builders during this phase are 2-fold: to maximise fat loss and minimise muscle mass loss. Fat loss requires that the bodybuilder go into negative energy balance usually by a combination of energy restriction and increased energy expenditure via aerobic exercise. However, if negative energy balance is too severe, loss of muscle mass is likely.[39] Maintenance of muscle mass requires that the bodybuilder is able to maintain his/her training intensity and volume. The high intensity, anaerobic nature of resistance training requires adequate muscle glycogen stores and thus dietary carbohydrate. Because adequate dietary carbohydrate is required for intense training it is unlikely that very low carbohydrate diets will achieve the goal of muscle mass maintenance. Diets such as the Atkins' diet *(ad libitum* diet ~68% fat, ~5% carbohydrate, ~27% protein) are very likely not conducive to muscle mass maintenance in body builders who train intensely. This is despite the fact that the Atkins' diet may result in greater fat loss than the conventional low-fat, high-carbohydrate diet.[59-61] An often overlooked reason to have a high-protein content of a bodybuilding diet is that it takes much more energy to metabolise protein than it does carbohydrate or fat and resting energy expenditure is proportional to the protein intake.

Nair et al.[62] reported that energy expenditure 2.5 hours after ingestion of a 300 kcal (1.25MJ) meal of protein was 15% of energy intake while that of fat was 7%, and carbohydrate was 6%. Similarly, Johnston et al.[63] reported that meal-induced thermogenesis was approximately 2-fold higher for a low-carbohydrate, high-protein, low-fat meal (30% complex carbohydrate, 10% simple sugar, 30% protein, 30% fat) than a high-carbohydrate, moderate-protein, low-fat meal (50% complex carbohydrate, 10% simple sugar, 15% protein, 25% fat) 2.5 hours after meal ingestion. Recently, Layman et al.[64] reported that a hypoenergetic high-protein diet (1700 kcal/day; 41% carbohydrate, 30% protein, 29% fat with a carbohydrate to protein ratio of 1.4) resulted in a significantly greater fat-to-lean mass loss (6.3 g/g) than a hypoenergetic, high-carbohydrate diet (1700 kcal/day; 58% carbohydrate, 16% protein, 26% fat with a carbohydrate to protein ratio of 3.5) in which the loss of fat-to-lean mass loss was 3.8 g/g. Similarly, Farnsworth et al.[65] reported that a hypoenergetic high protein diet (~1400 kcal; 44% carbohydrate, 27% protein, 29% fat) resulted in less lean mass loss (0.1kg) relative to a standard protein diet (1.5kg) [~1400kcal; 57% carbohydrate, 16% protein, 27% fat).

Skov et al.[66] examined the effects of high (25%) and low (12%) protein intake when individuals ingested an *ad libitum*, reduced-fat diet on weight loss in obese individuals. The difference in energy intake was made up by carbohydrate. They reported that in 6 months, the individuals in the low-protein group lost 5.1kg while those in the high-protein group lost 8.9kg ($p < 0.001$). In addition, 35% of the individuals in the high-protein group lost >10kg while only 9% lost this amount in the low-protein group. In a companion paper, Parker et al.[67] reported that in women, the high-protein diet resulted in significantly greater total and abdominal fat loss than the low-protein diet; however, no effect was observed in men. It appears well established that protein is much more thermogenic than carbohydrate and fat,[62,63] and the majority of data suggest that having a higher percentage of the diet as protein (~25–30%) may result in greater fat loss relative to fat-free mass loss than lower protein diets (~15%).[64,65] However, not all studies have reported that high-protein diets are more efficacious than lower protein diets. In individuals with type-2 diabetes mellitus, Luscombe et al.,[68] reported that a high-protein diet (28% protein; 42% carbohydrate) was no more efficacious for weight loss than a low-protein diet (16% protein; 55% carbohydrate) during 8 weeks of energy restriction (1600 kcal/day).

Changing the macronutrient composition of an individual's diet can result in weight loss despite the ingestion of the same amount of energy. Assuming that individuals are in energy balance on a 3000 kcal/day diet and that protein has a thermic effect that is 20% of the energy ingested,[69] while fat has a thermic effect of only 2% of energy ingested,[69] increasing the dietary protein percentage from 15% to 30% and reducing the fat percentage from 40% of energy intake to 25% of energy intake would result in the extra expenditure of 81 kcal/day and 29 565 kcal/year. Assuming, 3500 kcal is 0.455kg of fat, this would result in the loss of 3.8kg of fat in a year, which is not a trivial amount. This occurs as a result of changing the macronutrient composition without reducing dietary energy intake. Thus, adding protein at the expense of fat will add significantly to energy expenditure over time.

Walberg et al.[70] performed an investigation in which they compared two hypoenergetic diets (18 kcal/kg/day) one of which was moderate in protein (0.8 g/kg/day) and high in carbohydrate (70% carbohydrate) [13% fat] with another which was high in protein (1.6 g/kg/day) and moderate in carbohydrate (50% carbohydrate) approximately 50% carbohydrate (15% fat) for 7 days and examined the effects on nitrogen balance and muscular endurance in weight-trained individuals. They reported that the individuals on the moderate-protein/high-carbohydrate diet went into negative nitrogen balance (−3.19 g/day) while those in the high-protein/moderate-carbohydrate group were in positive nitrogen balance (4.13 g/day). However, there was a significant decline (22.4%) in quadriceps muscle endurance for the high-protein/moderate-carbohydrate group over the 7-day study. On the surface it would appear that the high-protein diet was beneficial in enhancing nitrogen retention but was detrimental because of low-glycogen stores due to the macronutrient composition. However, the degree of energy restriction was very large (−48.6%) as evidenced by the large reduction in bodyweight in the experimental groups (3.6 and 4.0kg for high-protein/moderate-carbohydrate and high-carbohydrate/moderate-protein groups, respectively) over 7 days.

It is well established that protein requirements increase with low energy intakes as a result of amino acid oxidation for energy.[71] Thus, the large reduction in energy intake likely increased protein requirements. Furthermore, the carbohydrate intake on the moderate carbohydrate diet was only 2.25 g/kg. Thus, the finding of negative nitrogen balance on the moderate-protein/high-carbohydrate diet and greater fatigability on the high-protein/moderate-carbohydrate diet was confounded by the low total energy intake, which did not supply adequate dietary protein to maintain nitrogen balance nor adequate carbohydrate to maintain adequate glycogen levels. This exemplifies the importance of a more moderate energy restriction to maintain adequate carbohydrate and protein intake. It is likely that had a more moderate energy restriction been used in the study by Walberg et al.,[72] a 50% carbohydrate, 30% protein diet would have provided adequate carbohydrate to maintain muscular endurance and adequate protein to maintain nitrogen balance.

Table I. Pre- and post-exercise macronutrient intake for optimal protein synthesis, muscle glycogen synthesis and inhibition of muscle proteolysis

	Pre-exercise (15 min prior)	Immediately post-exercise	2h post-exercise
Amino acids/protein	>6g of essential amino acids	>6g of essential amino acids	Unknown
Carbohydrate	1 g/kg	1.2 g/kg high-glycaemic index	1.2 g/kg high-glycaemic-index

6. Recommendations for Pre- and Post-Training Session Nutrition

Because pre-exercise carbohydrate feedings appear to augment performance during resistance exercise sessions,[21] and carbohydrate ingestion increases protein synthesis,[43] and decreases measures of proteolysis,[43,48] and because muscle glycogen levels are augmented by carbohydrate ingestion we recommend ingesting 1 g/kg of high-glycaemic-index carbohydrate 15 minutes prior to a resistance exercise session. We also suggest that at least 6g of amino acids/protein be ingested prior to a resistance exercise session as this has been shown to augment muscle protein synthesis relative to ingesting it after resistance exercise.[45] Immediately post-exercise we suggest ingesting at least 6g of amino acids/protein and 1.2g of high-glycaemic-index carbohydrate/kg/hour for 4 hours in order to stimulate protein synthesis,[43,44,49] reduce proteolysis[43,48] and maximally stimulate muscle glycogen resynthesis.[58] These suggestions are summarised in table I.

7. Factors Influencing Fat-Free Mass Loss During Energy Restriction

To our knowledge, there are no data examining factors that dictate the degree of fat-free mass loss during energy restriction in body builders. There are data, however, from normal weight and obese individuals undergoing energy restriction.[39] There appears to be two clear factors that act to determine the amount of fat-free mass lost during energy restriction: (i) the initial amount of body fat and; (ii) the degree of energy restriction. Individuals with more body fat lose less fat-free mass than their lean counterparts when undergoing the same degree of energy restriction. Furthermore, the greater the degree of energy restriction, the greater the loss of fat-free mass. These two findings may have important implications for the competitive bodybuilder. First, at the beginning of the pre-contest diet when body fat levels are relatively higher than those on the day of the contest, greater energy restriction can be undertaken. As the contest date arrives and body fat levels are reduced to lower levels, less of a reduction in energy intake should be undertaken in an effort to preserve fat-free mass. The implications of the degree of energy restriction affecting fat-free mass loss, suggests that extreme energy restriction during the pre-contest phase will cause greater fat-free mass loss and therefore the energy restriction should not be drastic. Unfortunately, it is difficult to put an exact number on the level of energy restriction that is too great due to inter-individual variability.

8. Conclusion

Optimal off-season resistance training, in which the major goal is to add muscle mass, requires a positive energy balance, a moderate-to-high carbohydrate intake to fuel resistance exercise sessions, and a protein intake of 25–30% of total energy intake. Furthermore, dietary fat should be adequate (~15–20% of total energy intake with some saturated fat) in an attempt to prevent a decline in circulating testosterone levels. Optimal pre-contest preparation goals are the retention of muscle mass and a reduction of body fat, the latter of which requires a negative energy balance. A moderate level of carbohydrate should be ingested to maintain workout intensity and an adequate protein intake will help prevent muscle mass loss and maintain a relatively high thermic effect. The timing, amount and type of macronutrient ingestion have important effects on protein synthesis and degradation as well as muscle glycogen resynthesis.

Acknowledgements

No sources of funding were used to assist in the preparation of this review. The authors have no conflicts of interest that are directly relevant to the content of this review.

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Correspondence and offprints: Dr *Charles P. Lambert*, Nutrition, Metabolism, and Exercise Laboratory, Donald W. Reynolds Department of Geriatrics,, University of Arkansas for Medical Sciences, Little Rock, AR 72205, USA.
E-mail: LambertCharlesP@uams.edu

