

REVIEW

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Evidence-based recommendations for natural bodybuilding contest preparation: nutrition and supplementation

Eric R Helms^{1*}, Alan A Aragon² and Peter J Fitschen³

Abstract

The popularity of natural bodybuilding is increasing; however, evidence-based recommendations for it are lacking. This paper reviewed the scientific literature relevant to competition preparation on nutrition and supplementation, resulting in the following recommendations. Caloric intake should be set at a level that results in bodyweight losses of approximately 0.5 to 1%/wk to maximize muscle retention. Within this caloric intake, most but not all bodybuilders will respond best to consuming 2.3-3.1 g/kg of lean body mass per day of protein, 15-30% of calories from fat, and the remainder of calories from carbohydrate. Eating three to six meals per day with a meal containing 0.4-0.5 g/kg bodyweight of protein prior and subsequent to resistance training likely maximizes any theoretical benefits of nutrient timing and frequency. However, alterations in nutrient timing and frequency appear to have little effect on fat loss or lean mass retention. Among popular supplements, creatine monohydrate, caffeine and beta-alanine appear to have beneficial effects relevant to contest preparation, however others do not or warrant further study. The practice of dehydration and electrolyte manipulation in the final days and hours prior to competition can be dangerous, and may not improve appearance. Increasing carbohydrate intake at the end of preparation has a theoretical rationale to improve appearance, however it is understudied. Thus, if carbohydrate loading is pursued it should be practiced prior to competition and its benefit assessed individually. Finally, competitors should be aware of the increased risk of developing eating and body image disorders in aesthetic sport and therefore should have access to the appropriate mental health professionals.

Keywords: Hypertrophy, Calories, Frequency, Nutrient, Body fat, Resistance training, Competition

Introduction

The popularity of natural bodybuilding is increasing rapidly. In the United States, over 200 amateur natural (drug tested) bodybuilding contests occurred during 2013 and the number of contests is expected to increase in 2014 [1]. Preparation for bodybuilding competition involves drastic reductions in body fat while maintaining muscle mass. This is typically achieved through a decreased caloric intake, intense strength training, and increased cardiovascular exercise. Competitors partake in numerous dietary and supplementation strategies to prepare for a contest. Some have a strong scientific basis;

however, many do not. Therefore, the purpose of this article is to review the scientific literature on topics relevant to nutrition and supplementation for bodybuilding competition preparation. Dietary modifications during the last week to enhance muscle definition and fullness (peaking) and psychosocial issues will also be covered. Ultimately, evidence-based recommendations will be made for nutrition, supplementation, and "peak week" strategies for natural bodybuilders. As a final note, this paper does not cover training recommendations for natural bodybuilding and the training methodology used will interact with and modify the effects of any nutritional approach.

Methods

PubMed, MEDLINE, SPORTDiscus and CINAHL electronic databases were searched online. Each author was

* Correspondence: eric.helms@aut.ac.nz

¹Sport Performance Research in New Zealand (SPRINZ) at AUT Millennium Institute, AUT University, 17 Antares Place, Mairangi Bay, Auckland 0632, New Zealand

Full list of author information is available at the end of the article

assigned a portion of the manuscript to write specific to their area(s) of expertise. Authors performed searches for key words associated with their portion(s) of the manuscript; calories and macronutrients, nutrient timing and meal frequency, dietary supplementation, psychosocial issues and “peak week” were the selected topics. The publications obtained were carefully screened for studies that included healthy humans or humans in a caloric deficit. Long-term human studies focusing on hypertrophy and body fat loss were preferentially selected; however, acute studies and/or studies using animal models were selected in the absence of adequate long-term human studies. In addition, author names and reference lists were used for further search of the selected papers for related references. As this review is intended to be an evidence-based guide and the available data relevant to natural bodybuilding is extremely limited, a narrative review style was chosen.

Nutrition

Calories and macronutrients

Competitive bodybuilders traditionally follow two to four month diets in which calories are decreased and energy expenditure is increased to become as lean as possible [2-6]. In addition to fat loss, muscle maintenance is of primary concern during this period. To this end, optimal caloric intakes, deficits and macronutrient combinations should be followed while matching the changing needs that occur during competition preparation.

Caloric intake for competition

To create weight loss, more energy must be expended than consumed. This can be accomplished by increasing caloric expenditure while reducing caloric intake. The size of this caloric deficit and the length of time it is maintained will determine how much weight is lost. Every pound of pure body fat that is metabolized yields approximately 3500 kcals, thus a daily caloric deficit of 500 kcals theoretically results in fat loss of approximately one pound per week if the weight loss comes entirely from body fat [7]. However, a static mathematical model does not represent the dynamic physiological adaptations that occur in response to an imposed energy deficit [8]. Metabolic adaptation to dieting has been studied in overweight populations and when observed, reductions in energy expenditure amount to as little as 79 kcal/d [9], to as much as 504 kcal/d beyond what is predicted from weight loss [10]. Metabolic adaptations to bodybuilding contest preparation have not been studied however; non-overweight men who consumed 50% of their maintenance caloric intake for 24 weeks and lost one fourth of their body mass experienced a 40% reduction in their baseline energy expenditure. Of that 40% reduction 25% was due to weight loss, while metabolic

adaptation accounted for the remaining 15% [11]. Therefore, it should be expected that the caloric intake at which one begins their preparation will likely need to be adjusted over time as body mass decreases and metabolic adaptation occurs. A complete review of metabolic adaptation to dieting in athletes is beyond the scope of this review. However, coaches and competitors are encouraged to read the recent review on this topic by Trexler et al. [12] which covers not only the physiology of metabolic adaptation, but also potential methods to mitigate its negative effects.

In determining an appropriate caloric intake, it should be noted that the tissue lost during the course of an energy deficit is influenced by the size of the energy deficit. While greater deficits yield faster weight loss, the percentage of weight loss coming from lean body mass (LBM) tends to increase as the size of the deficit increases [7,13-15]. In studies of weight loss rates, weekly losses of 1 kg compared to 0.5 kg over 4 weeks resulted in a 5% decrease in bench press strength and a 30% greater reduction in testosterone levels in strength training women [16]. Weekly weight loss rates of 1.4% of bodyweight compared to 0.7% in athletes during caloric restriction lasting four to eleven weeks resulted in reductions of fat mass of 21% in the faster weight loss group and 31% in the slower loss group. In addition, LBM increased on average by 2.1% in the slower loss group while remaining unchanged in the faster loss group. Worthy of note, small amounts of LBM were lost among leaner subjects in the faster loss group [13].

Therefore, weight loss rates that are more gradual may be superior for LBM retention. At a loss rate of 0.5 kg per week (assuming a majority of weight lost is fat mass), a 70 kg athlete at 13% body fat would need to be no more than 6 kg to 7 kg over their contest weight in order to achieve the lowest body fat percentages recorded in competitive bodybuilders following a traditional three month preparation [4,6,17-20]. If a competitor is not this lean at the start of the preparation, faster weight loss will be required which may carry a greater risk for LBM loss.

In a study of bodybuilders during the twelve weeks before competition, male competitors reduced their caloric intake significantly during the latter half and subsequently lost the greatest amount of LBM in the final three weeks [21]. Therefore, diets longer than two to four months yielding weight loss of approximately 0.5 to 1% of bodyweight weekly may be superior for LBM retention compared to shorter or more aggressive diets. Ample time should be allotted to lose body fat to avoid an aggressive deficit and the length of preparation should be tailored to the competitor; those leaner dieting for shorter periods than those with higher body fat percentages. It must also be taken into consideration that the leaner the competitor becomes the greater the risk for LBM loss

[14,15]. As the availability of adipose tissue declines the likelihood of muscle loss increases, thus it may be best to pursue a more gradual approach to weight loss towards the end of the preparation diet compared to the beginning to avoid LBM loss.

Determining macronutrient intake

Protein Adequate protein consumption during contest preparation is required to support maintenance of LBM. Athletes require higher protein intakes to support increased activity and strength athletes benefit from higher intakes to support growth of LBM [5,22-28]. Some researchers suggest these requirements increase further when athletes undergo energy restriction [13,16,22,28-33]. Furthermore, there is evidence that protein requirements are higher for leaner individuals in comparison to those with higher body fat percentages [7,33,34].

The collective agreement among reviewers is that a protein intake of 1.2-2.2 g/kg is sufficient to allow adaptation to training for athletes whom are at or above their energy needs [23-28,35-38]. However, bodybuilders during their contest preparation period typically perform resistance and cardiovascular training, restrict calories and achieve very lean conditions [2-6,17-21]. Each of these factors increases protein requirements and when compounded may further increase protein needs [33]. Therefore, optimal protein intakes for bodybuilders during contest preparation may be significantly higher than existing recommendations.

In support of this notion, Butterfield et al. [22] found that male athletes running five to 10 miles per day during a slight caloric deficit were in a significant negative nitrogen balance despite consuming 2 g/kg of protein daily. Celejowa et al. [39] showed that five out of 10 competitive weight lifters achieved a negative nitrogen balance over the course of a training camp while consuming an average protein intake of 2 g/kg. Out of these five, as many as three were in a caloric deficit. The authors concluded that a protein intake of 2-2.2 g/kg under these conditions only allows for a small margin of error before nitrogen losses occur.

Walberg et al. [32] examined the effects of two energy restricted isocaloric diets of differing protein intakes in 19 lean (9.1-16.7% body fat), male, non-competitive body builders. One group consumed a protein intake of 0.8 g/kg and higher carbohydrates, while the other consumed 1.6 g/kg of protein with lower carbohydrates. The length of the intervention was only one week, but nonetheless nitrogen losses occurred only in the lower protein group and LBM decreased by a mean of 2.7 kg in the 0.8 g/kg protein group and by a mean of 1.4 kg in the 1.6 g/kg protein group. While the high protein group mitigated LBM losses compared to the low protein group, they were not eliminated.

A recent study by Mettler et al. [29] employed the same basic methodology as Walberg et al. [32]. However, one group consumed a protein intake of 1 g/kg, while the other consumed 2.3 g/kg. The high-protein group lost significantly less LBM (0.3 kg) over the course of the two week intervention compared to the low-protein group (1.6 kg). Unlike Walberg et al. [32] calorie balance between diets was maintained by reducing dietary fat as opposed to carbohydrate to allow for the increase in protein.

While it appears that the 2.3 g/kg protein intervention in Mettler et al. [29] was superior for maintaining LBM compared to 1.6 g/kg in Walberg et al. [32] a recent study by Pasiakos et al. [40] found a trend towards the opposite. In this study, a non-significant trend of greater LBM retention occurred when subjects consumed 1.6 g/kg of protein compared to 2.4 g/kg of protein. However, the participants were intentionally prescribed low volume, low intensity resistance training "to minimize the potential of an unaccustomed, anabolic stimulus influencing study outcome measures". Thus, the non-anabolic nature of the training may not have increased the participants' protein requirements to the same degree as the participants in Mettler et al. [29] or to what would be expected among competitive bodybuilders.

Maestu et al. [6] did not observe a significant loss of LBM in a group of drug free bodybuilders consuming 2.5-2.6 g/kg of protein during the 11 weeks prior to competition. These results when considered alongside the works by Walberg et al. [32] and Mettler et al. [29] imply that the higher the protein intake, the lower the chance for LBM loss. However, it should be noted that this study did not include a low protein control and not all studies show a linear increase in LBM preservation with increases in protein [40]. Furthermore, two subjects did lose significant amounts of LBM (1.5 kg and 1.8 kg), and the authors noted that these specific bodybuilders were among the leanest of the subjects. These two subjects lost the majority of their LBM (approximately 1 kg) during the latter half of the intervention as their percentage of calories from protein increased from 28% to 32-33% by the end of the study. The group as a whole progressively decreased their calories by reducing all three macronutrients throughout the investigation. Thus, the two subjects uniquely increased their proportion of protein, possibly reducing fat and carbohydrate to the point of detriment [6]. That said it is also plausible that the lost LBM seen by these two subjects was necessary in order to achieve their low levels of body fat. It is unknown whether or not the lost LBM influenced their competitive outcome and it is possible that had the competitors not been as lean, they may have retained more LBM but also not have placed as well.

In a review by Phillips and Van Loon [28], it is suggested that a protein intake of 1.8-2.7 g/kg for athletes

training in hypocaloric conditions may be optimal. While this is one of the only recommendations existing that targets athletes during caloric restriction, this recommendation is not given with consideration to bodybuilders performing concurrent endurance and resistance training at very low levels of body fat. However, the recently published systematic review by Helms et al. [33] on protein intakes in resistance-trained, lean athletes during caloric restriction suggests a range of 2.3-3.1 g/kg of LBM, which may be more appropriate for bodybuilding. Moreover, the authors suggest that the lower the body fat of the individual, the greater the imposed caloric deficit and when the primary goal is to retain LBM, the higher the protein intake (within the range of 2.3-3.1 g/kg of LBM) should be.

Carbohydrate High carbohydrate diets are typically thought to be the athletic performance standard. However, like protein, carbohydrate intake needs to be customized to the individual. Inadequate carbohydrate can impair strength training [41] and consuming adequate carbohydrate prior to training can reduce glycogen depletion [42] and may therefore enhance performance.

While it is true that resistance training utilizes glycogen as its main fuel source [43], total caloric expenditure of strength athletes is less than that of mixed sport and endurance athletes. Thus, authors of a recent review recommend that carbohydrate intakes for strength sports, including bodybuilding, be between 4–7 g/kg depending on the phase of training [26]. However, in the specific case of a bodybuilder in contest preparation, achieving the necessary caloric deficit while consuming adequate protein and fat would likely not allow consumption at the higher end of this recommendation.

Satiety and fat loss generally improve with lower carbohydrate diets; specifically with higher protein to carbohydrate ratios [44-49]. In terms of performance and health, low carbohydrate diets are not necessarily as detrimental as typically espoused [50]. In a recent review, it was recommended for strength athletes training in a calorically restricted state to reduce carbohydrate content while increasing protein to maximize fat oxidation and preserve LBM [28]. However, the optimal reduction of carbohydrate and point at which carbohydrate reduction becomes detrimental likely needs to be determined individually.

One comparison of two isocaloric, energy restricted diets in bodybuilders showed that a diet that provided adequate carbohydrate at the expense of protein (1 g/kg) resulted in greater LBM losses compared to a diet that increased protein (1.6 g/kg) through a reduction of carbohydrate [32]. However, muscular endurance was degraded in the lower carbohydrate group. In a study of athletes taking in the same amount of protein (1.6 g/kg) during weight loss, performance decrements and LBM

losses were avoided when adequate carbohydrate was maintained and dietary fat was lowered [13]. Mettler, et al. [29] also found that a caloric reduction coming from dietary fat while maintaining adequate carbohydrate intake and increasing protein to 2.3 g/kg maintained performance and almost completely eliminated LBM losses in resistance trained subjects. Finally, in Pasiakos et al. [40] participants undergoing an equal caloric deficit and consuming the same amount of protein as those observed in Mettler et al. [29] lost three times the amount of LBM over the same time period (0.9 kg in the first two weeks of energy restriction observed by Pasiakos versus 0.3 kg observed by Mettler). One key difference between these studies was the highest protein group in Mettler et al. [29] consumed a 51% carbohydrate diet while the comparable group in Pasiakos et al. [40] consumed a 27% carbohydrate diet. While performance was not measured, the participants in Pasiakos et al. [40] performing sets exclusively of 15 repetitions very likely would have experienced decrements in performance due to this carbohydrate intake level [32]. The difference in training protocols or a nutritionally mediated decrement in training performance could have either or both been components that lead to the greater losses of LBM observed by Pasiakos et al. [40].

While it appears low carbohydrate, high protein diets can be effective for weight loss, a practical carbohydrate threshold appears to exist where further reductions negatively impact performance and put one at risk for LBM losses. In support of this notion, researchers studying bodybuilders during the final 11 weeks of contest preparation concluded that had they increased carbohydrate during the final weeks of their diet they may have mitigated metabolic and hormonal adaptations that were associated with reductions in LBM [6].

Therefore, once a competitor has reached or has nearly reached the desired level of leanness, it may be a viable strategy to reduce the caloric deficit by an increase in carbohydrate. For example, if a competitor has reached competition body fat levels (lacking any visible subcutaneous fat) and is losing half a kilogram per week (approximately a 500 kcals caloric deficit), carbohydrate could be increased by 25-50 g, thereby reducing the caloric deficit by 100-200 kcals in an effort to maintain performance and LBM. However, it should be noted that like losses of LBM, decrements in performance may not affect the competitive outcome for a bodybuilder. It is possible that competitors who reach the leanest condition may experience unavoidable drops in performance.

Fat The importance of carbohydrate and protein in sports nutrition is often emphasized over that of dietary fat. Subsequently, recommendations typically focus on maintaining adequate fat intake while emphasizing carbohydrate to

fuel performance and protein to build and repair LBM. However, there is evidence that dietary fat influences anabolic hormone concentrations which may be of interest to bodybuilders attempting to maintain LBM while dieting [5,26,51,52].

Reductions in the percentage of dietary fat in isocaloric diets from approximately 40% to 20% has resulted in modest, but significant, reductions in testosterone levels [53,54]. However, distinguishing the effects of reducing total dietary fat on hormonal levels from changes in caloric intake and percentages of saturated and unsaturated fatty acids in the diet is difficult [51,52,55]. In a study by Volek et al. [51], correlations were found between testosterone levels, macronutrient ratios, types of lipids, and total dietary fat, illustrating a complex interaction of variables. In a similar study of resistance trained males, correlations were found between testosterone, protein, fat and saturated fat which lead the researchers to conclude that diets too low in fat or too high in protein might impair the hormonal response to training [52].

Competing bodybuilders must make an obligatory caloric reduction. If a reduction in fat is utilized, it may be possible to attenuate a drop in testosterone by maintaining adequate consumption of saturated fat [5]. However, a drop in testosterone does not equate to a reduction in LBM. In direct studies of resistance trained athletes undergoing calorically restricted high protein diets, low fat interventions that maintain carbohydrate levels [13,29] appear to be more effective at preventing LBM losses than lower carbohydrate, higher fat approaches [32,40]. These results might indicate that attempting to maintain resistance training performance with higher carbohydrate intakes is more effective for LBM retention than attempting to maintain testosterone levels with higher fat intakes.

Body composition and caloric restriction may play greater roles in influencing testosterone levels than fat intake. During starvation, a reduction in testosterone occurs in normal weight, but not obese, males [56]. In addition, rate of weight loss may influence testosterone levels. Weekly target weight loss rates of 1 kg resulted in a 30% reduction in testosterone compared to target weight loss rates of 0.5 kg per week in resistance trained women of normal weight [16]. Additionally, an initial drop in testosterone occurred in the first six weeks of contest preparation in a group of drug free bodybuilders despite various macronutrient percentages [6]. Finally, in a one year case study of a natural competitive bodybuilder, testosterone levels fell to one fourth their baseline values three months into the six month preparation period. Levels then fully recovered three months into the six month recovery period. Testosterone did not decline further after the initial drop at the three month mark despite a slight decrease in fat intake from 27% to 25% of calories at the six month mark. Furthermore, the

quadrupling of testosterone during the recovery period from its suppressed state back to baseline was accompanied by a 10 kg increase in body mass and a 1000 kcal increase in caloric intake. However, there was only a minor increase in calories from fat (percentage of calories from fat during recovery was between 30 and 35%) [57]. Finally, these testosterone changes in men appear mostly related to energy availability (body fat content and energy balance), and not surprisingly low-levels of sustained energy availability are also the proposed cause of the hormonal disturbance "athletic amenorrhea" in women [58]. Thus, the collective data indicates that when extremely lean body compositions are attained through extended, relatively aggressive dieting, the caloric deficit and loss of body fat itself may have a greater impact on testosterone than the percentage of calories coming from dietary fat.

While cogent arguments for fat intakes between 20 to 30% of calories have been made to optimize testosterone levels in strength athletes [59], in some cases this intake may be unrealistic in the context of caloric restriction without compromising sufficient protein or carbohydrate intakes. While dieting, low carbohydrate diets may degrade performance [32] and lead to lowered insulin and IGF-1 which appear to be more closely correlated to LBM preservation than testosterone [6]. Thus, a lower end fat intake between 15-20% of calories, which has been previously recommended for bodybuilders [5], can be deemed appropriate if higher percentages would reduce carbohydrate or protein below ideal ranges.

Ketogenic diets and individual variability

Some bodybuilders do use very-low carbohydrate, "ketogenic diets" for contest preparation [60,61]. While these diets have not been sufficiently studied in bodybuilders, some study of ketogenic diets has occurred in resistance trained populations. In an examination of the effects of a 1 week ketogenic diet (5.4% of calories from carbohydrate) in subjects with at least 2 years of resistance training experience, Sawyer et al. [62] observed slight decreases in body fat among female participants and maintenance or slight increases in measures of strength and power among both male and female participants. However, it is difficult to draw conclusions due to the very short term nature of this study and due to an ad libitum implementation of the ketogenic diet. As implemented in this study, besides a reduction in carbohydrate and an increase in dietary fat, the ketogenic diet resulted in an average reduction of 381 calories per day and an increase of 56 g of protein per day compared to the participants' habitual diets. Thus, it is unclear whether the improvements in body composition and performance can be attributed to the low-carbohydrate and high-fat nature of the diets or rather a decrease in

calories and an increase in protein. At least with regards to weight loss, previous research indicates that the often concomitant increase in protein observed in very low carbohydrate diets may actually be the key to their success [63].

The only research on strength athletes following ketogenic diets for longer periods is a study of gymnasts in which they were observed to maintain strength performance and lose more body fat after 30 days on a ketogenic diet in comparison to 30 days on a traditional western diet [64]. However, this study's sample size was limited ($n = 8$) and it was not a controlled study of an intentional fat-loss phase such as seen among bodybuilders during competition preparation. Therefore, more study is needed in resistance trained populations and bodybuilders before definitive recommendations can be made to support ketogenic diets.

However, the research that does exist challenges traditional views on carbohydrate and anaerobic performance. Despite the common belief that carbohydrate is the sole fuel source for weight training, intramuscular triglyceride is used during short term heavy resistance training [65] and likely becomes an increasingly viable fuel source for those adapted to high-fat low-carbohydrate diets. While some might suggest that this implies a ketogenic diet could be a viable option for contest preparation, a trend of decreased performance and impaired maintenance of FFM is associated with lower carbohydrate intakes in the majority of studies included in this review.

While it is our contention that the majority of the evidence indicates that very-low carbohydrate diets should be avoided for contest preparation (at least until more research is performed), it must be noted that there is a high degree of variability in the way that individuals respond to diets. Carbohydrate and fat utilization as a percentage of energy expenditure at rest and various intensities has as much as a four-fold difference between individual athletes; which is influenced by muscle fiber-composition, diet, age, training, glycogen levels and genetics [66]. Additionally, individuals that are more insulin sensitive may lose more weight with higher-carbohydrate low-fat diets while those more insulin resistant may lose more weight with lower-carbohydrate higher-fat diets [67].

Due to this individual variability, some popular commercial bodybuilding literature suggests that somatotype and/or body fat distribution should be individually assessed as a way of determining macronutrient ratios. However, there is no evidence of any relationships with bone structure or regional subcutaneous fat distribution with any response to specific macronutrient ratios in bodybuilders or athletic populations. Bodybuilders, like others athletes, most likely operate best on balanced macronutrient intakes tailored to the energy demands of their sport [68].

In conclusion, while the majority of competitors will respond best to the fat and carbohydrate guidelines we propose, the occasional competitor will undoubtedly respond better to a diet that falls outside of these suggested ranges. Careful monitoring over the course of a competitive career is required to determine the optimal macronutrient ratio for pre-contest dieting.

Macronutrient recommendations summary

After caloric intake is established based on the time frame before competition [69], body composition of the athlete [14,15,34], and keeping the deficit modest to avoid LBM losses [13,16], macronutrients can be determined within this caloric allotment. Table 1 provides an overview of these recommendations.

If training performance degrades it may prove beneficial to decrease the percentage of calories from dietary fat within these ranges in favor of a greater proportion of carbohydrate. Finally, while outside of the norm, some competitors may find that they respond better to diets that are higher in fat and lower in carbohydrate than recommended in this review. Therefore, monitoring of individual response over a competitive career is suggested.

Nutrient timing

Traditional nutrient timing guidelines are typically based on the needs of endurance athletes. For example, it is common lore that post-exercise carbohydrate must elicit a substantial glycemic and insulinemic response in order to optimize recovery. The origin of this recommendation can be traced back to 1988, when Ivy et al. [70] put fasted subjects through a glycogen-depleting cycling bout and compared the rate of glycogen resynthesis from a carbohydrate solution (2 g/kg) consumed either immediately after, or two hours after the bout. Glycogen storage was 2–3 times faster in the immediate condition during four hours post-exercise resulting in greater glycogen storage at four hours.

These findings initiated the faster-is-better post-exercise guideline for carbohydrate. However, complete glycogen resynthesis to pre-trained levels can occur well within 24 hours given sufficient total carbohydrate intake. Jentjens and Jeukendrup [71] suggest that a between-bout period of eight hours or less is grounds for maximally

Table 1 Dietary recommendations for bodybuilding contest preparation

Diet component	Recommendation
Protein (g/kg of LBM)	2.3-3.1 [33]
Fat (% of total calories)	15-30% [5,59]
Carbohydrate (% of total calories)	remaining
Weekly weight loss (% of body weight)	0.5-1% [13,16]

expediting glycogen resynthesis. Therefore, the urgency of glycogen resynthesis is almost an exclusive concern of endurance athletes with multiple glycogen-depleting events separated by only a few hours. Bodybuilders in contest preparation may exceed a single training bout per day (e.g., weight-training in the morning, cardio in the evening). However, bodybuilders do not have the same performance objectives as multi-stage endurance competition, where the same muscle groups are trained to exhaustion in a repeated manner within the same day. Furthermore, resistance training bouts are typically not glycogen-depleting. High-intensity (70-80% of 1 RM), moderate-volume (6-9 sets per muscle group) bouts have been seen to reduce glycogen stores by roughly 36-39% [72,73].

A more relevant question to bodybuilding may be whether protein and/or amino acid timing affect LBM maintenance. With little exception [74], acute studies have consistently shown that ingesting protein/essential amino acids and carbohydrate near or during the training bout can increase muscle protein synthesis (MPS) and suppress muscle protein breakdown [75-79]. However, there is a disparity between short- and long-term outcomes in studies examining the effect of nutrient timing on resistance training adaptations.

To-date, only a minority of chronic studies have shown that specific timing of nutrients relative to the resistance training bout can affect gains in muscular size and/or strength. Cribb and Hayes [80] found that timing a supplement consisting of 40 g protein, 43 g carbohydrate, and 7 g creatine immediately pre- and post-exercise resulted in greater size and strength gains than positioning the supplement doses away from the training bout. Additionally, Esmarck et al. [81] observed greater hypertrophy in subjects who ingested a supplement (10 g protein, 8 g carbohydrate, 3 g fat) immediately post-exercise than subjects who delayed the supplement 2 hours post-exercise.

In contrast, the majority of chronic studies have not supported the effectiveness of timing nutrients (protein in particular) closely around the training bout. Burk et al. [82], found that a *time-divided* regimen (two 35 g protein doses consumed at far-off points in the morning and evening away from the afternoon training bout) caused slightly better gains in squat strength and fat-free mass than the *time-focused* regimen, where the protein supplement doses were consumed in the morning, and then again immediately prior to the resistance training bout. Hoffman et al. [83] found no significant differences in strength gains or body composition when comparing an immediate pre- and post-exercise supplement ingestion (each dose provided 42 g protein) with the supplement ingested distantly separate from each side of the training bout. This lack of effect was attributed to the subjects' sufficient daily protein consumption combined with their advanced lifting status. Wycherley et al. [84]

examined the effects of varying nutrient timing on overweight and obese diabetics. A meal containing 21 g protein consumed immediately before resistance training was compared with its consumption at least two hours after training. No significant differences in weight loss, strength gain, or cardio metabolic risk factor reductions were seen. Most recently, Weisgarber et al. [85] observed no significant effect on muscle mass and strength from consuming whey protein immediately before or throughout resistance training.

It's important to note that other chronic studies are referred to as nutrient timing studies, but have not matched total protein intake between conditions. These studies examined the effect of additional nutrient content, rather than examining the effect of different temporal placement of nutrients relative to the training bout. Thus, they cannot be considered true timing comparisons. Nevertheless, these studies have yielded inconsistent results. Willoughby et al. [86] found that 10 weeks of resistance training supplemented with 20 g protein and amino acids 1 hour pre- and post-exercise increased strength performance and MPS compared to an energy-matched carbohydrate placebo. Hulmi et al. [87] found that 21 weeks of supplementing 15 g of whey before and after resistance training increased size and altered gene expression favorably towards muscle anabolism in the vastus lateralis. In contrast to the previous 2 studies, Verdijk et al. [88] found no significant effect of 10 g protein timed immediately before and after resistance training over a 12-week period. The authors attributed this lack of effect to an adequate total daily protein intake. Recently, a 12-week trial by Erksine et al. [89] reported a lack of effect of 20 g protein taken pre- and post-exercise compared to placebo.

The disparity of outcomes between the acute and chronic studies could also potentially be due to a longer "anabolic window" than traditionally thought. Burd and colleagues [90] found that resistance training to failure can cause an increased anabolic response to protein feedings that can last up to 24 hours. Demonstrating the body's drive toward equilibrium, Deldicque et al. [91] observed a greater intramyocellular anabolic response in fasted compared to fed subjects given a post-exercise carbohydrate/protein/leucine mixture. This result suggests that the body is capable of anabolic supercompensation despite the inherently catabolic nature of fasted resistance training. These data, in addition to the previously discussed chronic studies, further support the idea that macronutrient totals by the end of the day may be more important than their temporal placement relative to the training bout.

There are additional factors that might explain the lack of consistent effectiveness of nutrient timing in chronic studies. Training status of the subjects could influence outcomes since novice trainees tend to respond

similarly to a wider variety of stimuli. Another possible explanation for the lack of timing effects is the protein dose used, 10–20 g, which may not be sufficient to elicit a maximal anabolic response. MPS rates have been shown to plateau with a post-exercise dose of roughly 20 g of high-quality protein [92]. However, in subsequent research on older subjects, Yang et al. [93] observed that an even higher post-exercise protein dose (40 g) stimulated MPS to a greater extent than 10 g or 20 g.

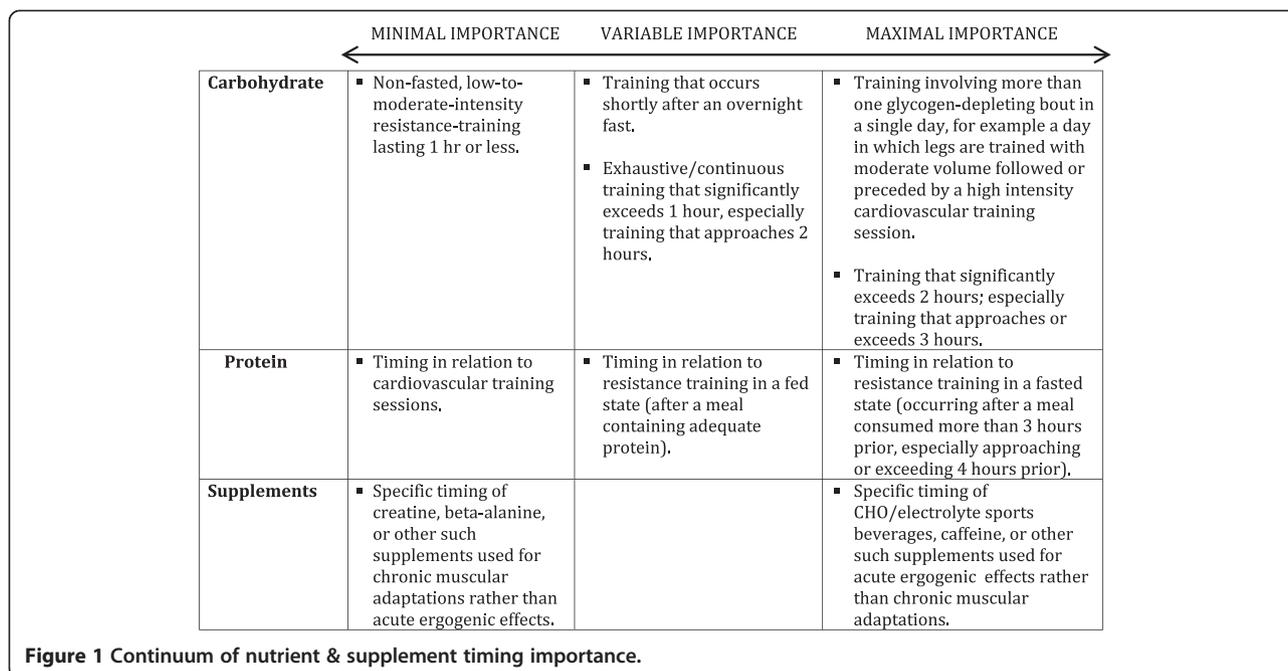
In addition to the paucity of studies using ample protein doses, there is a lack of investigation of protein-carbohydrate combinations. Only Cribb and Hayes [80] have compared substantial doses of both protein (40 g) and carbohydrate (43 g) taken immediately surrounding, versus far apart from both sides of the training bout. Nearly double the lean mass gains were seen in the proximally timed compared to the distally timed condition. However, acute studies examining the post-exercise anabolic response elicited by co-ingesting carbohydrate with protein have thus far failed to show significant effects given a sufficient protein dose of approximately 20–25 g [94,95]. These results concur with previous data indicating that only moderate insulin elevations (15–30 mU/L) are required to maximize net muscle protein balance in the presence of elevated plasma amino acids [96]. Koopman et al. [97] observed a similar lack of carbohydrate-mediated anabolic effect when protein was administered at 0.3 g/kg/hr in the post-exercise recovery period.

Questions remain about the utility of consuming protein and/or carbohydrate during bodybuilding-oriented training bouts. Since these bouts typically do not resemble endurance bouts lasting 2 hours or more, nutrient consumption during training is not likely to yield any additional performance-enhancing or muscle-sparing benefits if proper pre-workout nutrition is in place. In the exceptional case of resistance training sessions that approach or exceed two hours of exhaustive, continuous work, it might be prudent to employ tactics that maximize endurance capacity while minimizing muscle damage. This would involve approximately 8–15 g protein co-ingested with 30–60 g carbohydrate in a 6–8% solution per hour of training [98]. Nutrient timing is an intriguing area of study that focuses on what might clinch the competitive edge. In terms of practical application to resistance training bouts of typical length, Aragon and Schoenfeld [99] recently suggested a protein dose corresponding with 0.4–0.5 g/kg bodyweight consumed at both the pre- and post-exercise periods. However, for objectives relevant to bodybuilding, the current evidence indicates that the global macronutrient composition of the diet is likely the most important nutritional variable related to chronic training adaptations. Figure 1 below provides a continuum of importance with bodybuilding-specific context for nutrient timing.

Meal frequency

Previous optimal meal frequency studies have lacked structured resistance training protocols. Moreover, there are no studies that specifically examined meal frequency in bodybuilders, let alone during contest preparation conditions. Despite this limitation, the available research has consistently refuted the popular belief that a grazing pattern (smaller, more frequent meals) raises energy expenditure compared to a gorging pattern (larger, less frequent meals). Disparate feeding patterns ranging from two to seven meals per day have been compared in tightly controlled studies using metabolic chambers, and no significant differences in 24-hour thermogenesis have been detected [100,101]. It should be noted that irregular feeding patterns across the week, as opposed to maintaining a stable daily frequency, has been shown to decrease post-prandial thermogenesis [102] and adversely affect insulin sensitivity and blood lipid profile [103]. However, relevance of the latter findings might be limited to sedentary populations, since regular exercise is well-established in its ability to improve insulin sensitivity and blood lipids.

Bodybuilders typically employ a higher meal frequency in an attempt to optimize fat loss and muscle preservation. However, the majority of chronic experimental studies have failed to show that different meal frequencies have different influences on bodyweight or body composition [104–108]. Of particular interest is the research examining the latter, since the preservation of muscle mass during fat loss is a paramount concern in the pre-contest phase. A recent review by Varady [109] examined 11 daily caloric restriction (CR) studies and 7 intermittent calorie restriction (ICR) studies. CR involved a linear consumption of 15–60% of baseline needs every day, while ICR alternated ad libitum ‘feed’ days with ‘fast’ days involving partial or total food intake restriction. It was concluded that although both types have similar effects on total bodyweight reduction, ICR has thus far been more effective for retaining lean mass. Three of the ICR studies showed no significant decrease in LBM, while all of the CR studies showed decreased LBM. However, the majority of the ICR trials used bioelectrical impedance analysis (BIA) to measure body composition, while the majority of CR studies used dual X-ray absorptiometry (DXA) or magnetic resonance imaging (MRI). These methods have been shown to have greater accuracy than BIA [110–112], so the results of Varady’s [109] analysis should be interpreted with caution. Along these lines, Stote et al. [113] found that compared to three meals per day, one meal per day caused slightly more weight and fat loss. Curiously, the one meal per day group also showed a slight gain in lean mass, but this could have been due to the inherent error in BIA for body composition assessment.



To-date, only two experimental studies have used trained, athletic subjects. Iwao et al. [114] found that boxers consuming six meals a day lost less LBM and showed lower molecular measures of muscle catabolism than the same diet consumed in two meals per day. However, limitations to this study included short trial duration, subpar assessment methods, a small sample size, and a 1200 kcal diet which was artificially low compared to what this population would typically carry out in the long-term. It is also important to note that protein intake, at 20% of total kcal, amounted to 60 g/day which translates to slightly under 1.0 g/kg. To illustrate the inadequacy of this dose, Mettler et al. [29] showed that protein as high as 2.3 g/kg and energy intake averaging 2022 kcal was still not enough to completely prevent LBM loss in athletes under hypocaloric conditions. The other experimental study using athletic subjects was by Benardot et al. [115], who compared the effects of adding three 250 kcal between-meal snacks with the addition of a noncaloric placebo. A significant increase in anaerobic power and lean mass was seen in the snacking group, with no such improvements seen in the placebo group. However, it is not possible to determine if the superior results were the result of an increased meal frequency or increased caloric intake.

A relatively recent concept with potential application to meal frequency is that a certain minimum dose of leucine is required in order to stimulate muscle protein synthesis. Norton and Wilson [116] suggested that this threshold dose is approximately 0.05 g/kg, or roughly 3 g leucine per meal to saturate the mTOR signaling pathway and trigger MPS. A related concept is that MPS

can diminish, or become 'refractory' if amino acids are held at a constant elevation. Evidence of the refractory phenomenon was shown by Bohé et al. [117], who elevated plasma amino acid levels in humans and observed that MPS peaked at the 2-hour mark, and rapidly declined thereafter despite continually elevated blood amino acid levels. For the goal of maximizing the anabolic response, the potential application of these data would be to avoid spacing meals too closely together. In addition, an attempt would be made to reach the leucine threshold with each meal, which in practical terms would be to consume at least 30–40 g high-quality protein per meal. In relative agreement, a recent review by Phillips and Van Loon [28] recommends consuming one's daily protein requirement over the course of three to four isonitrogenous meals per day in order to maximize the acute anabolic response per meal, and thus the rate of muscle gain.

It is important to note that the leucine threshold and the refractory nature of MPS are not based on human feeding studies that measure concrete outcomes over the long-term. These ideas are largely based on mechanistic studies whose data was derived via steady intravenous infusion of amino acids [117,118]. Long-term studies are needed to determine if the refractory nature of MPS seen in acute infusion data would have any real impact on the gain or preservation of LBM at various meal frequencies.

Munster and Saris [119] recently shed further light on what might be optimal in the context of pre-contest dieting. Lean, healthy subjects underwent 36-hour periods in a respiration chamber. Interestingly, three meals per day resulted in higher protein oxidation and RMR,

along with lower overall blood glucose concentrations than an isoenergetic diet composed of 14 meals per day. The lower glucose AUC observed in this study is in agreement with previous research by Holmstrup et al. [120], who reported lower 12-hour glucose concentrations as a result of consuming three high-carbohydrate meals compared to the equivalent distributed over the course of six meals. Another interesting finding by Munster and Saris [119] was lower hunger and higher satiety ratings in the lower meal frequency condition. This finding concurred with previous work by Leidy et al. [121], who compared varying protein levels consumed across either three or six meals per day. Predictably, the higher-protein level (25% vs. 14%) promoted greater satiety. Interestingly, the higher meal frequency led to lower daily fullness ratings regardless of protein level. Meal frequency had no significant impact on ghrelin levels, regardless of protein intake. PYY, a gut peptide associated with satiety, was 9% lower in the higher meal frequency condition. However, Arciero et al. [122] recently found that six meals per day in a high-protein condition (35% of total energy) were superior to three meals with a high-protein or traditional protein intake (15% of total energy) for improving body composition in overweight subjects. The discrepancy between Leidy et al's short-term effects and Arciero's chronic effects warrants further study, preferably in subjects undergoing progressive resistance training.

Other common meal frequencies (i.e., 4 or 5 meals per day) have eluded scientific investigation until very recently. Adechian et al. [123] compared whey versus casein consumed in either a 'pulse' meal pattern (8/80/4/8%) or a 'spread' pattern (25/25/25/25%) over a six week hypocaloric period. No significant changes were seen in body composition between conditions. These outcomes challenge Phillips and Van Loon's recommendation for protein-rich meals throughout the day to be isonitrogenous (40). Moore et al. [124] compared evenly spaced distributions of two, four, and eight meals consumed after a fasted, acute bout of bilateral knee extension. A trend toward a small and moderate increase in net protein balance was seen in the four meal and eight meal conditions, respectively, compared to the two meal condition. Subsequent work by Areta et al. [125] using the same dosing comparison found that the four meal treatment (20 g protein per meal) caused the greatest increase in myofibrillar protein synthesis. A limitation of both of the previous studies was the absence of other macronutrients (aside from protein in whey) consumed during the 12-hour postexercise period. This leaves open questions about how a real-world scenario with mixed meals might have altered the outcomes. Furthermore, these short-term responses lack corroboration in chronic trials measuring body composition and/or exercise performance outcomes.

The evidence collectively suggests that extreme lows or highs in meal frequency have the potential to threaten lean mass preservation and hunger control during bodybuilding contest preparation. However, the functional impact of differences in meal frequency at moderate ranges (e.g., 3–6 meals per day containing a minimum of 20 g protein each) are likely to be negligible in the context of a sound training program and properly targeted total daily macronutrition.

Nutritional supplementation

When preparing for a bodybuilding contest, a competitor primarily focuses on resistance training, nutrition, and cardiovascular training; however, supplements may be used to further augment preparation. This section will discuss the scientific evidence behind several of the most commonly used supplements by bodybuilders. However, natural bodybuilding federations have extensive banned substance lists [126]; therefore, banned substances will be omitted from this discussion. It should be noted that there are considerably more supplements that are used by bodybuilders and sold on the market. However, an exhaustive review of all of the supplements commonly used by bodybuilders that often lack supporting data is beyond the scope of this paper. In addition, we have omitted discussion of protein supplements because they are predominantly used in the same way that whole food protein sources are used to reach macronutrient targets; however, interested readers are encouraged to reference the ISSN position stand on protein and exercise [127].

Creatine

Creatine monohydrate (CM) has been called the most ergogenic and safe supplement that is legally available [128]. Supplementation of healthy adults has not resulted in any reported adverse effects or changes in liver or kidney function [129]. Numerous studies have found significantly increased muscle size and strength when CM was added to a strength training program [130-134]. In many of these studies, 1-2 kg increases in total body mass were observed after CM loading of 20 g/day for 4–28 days [135]. However, the loading phase may not be necessary. Loading 20 g CM per day has been shown to increase muscle total creatine by approximately 20 percent and this level of muscle creatine was maintained with 2 g CM daily for 30 days [136]. However, the same study also observed a 20 percent increase in muscle creatine when 3 g CM was supplemented daily for 28 days, indicating the loading phase may not be necessary to increase muscle creatine concentrations.

Recently, alternative forms of creatine, such as creatine ethyl ester (CEE) and Kre Alkalyne (KA) have been marketed as superior forms of creatine to CM; however, as

of this time these claims have not been supported by scientific studies. Tallon and Child [137,138] found that a greater portion of CEE and KA are degraded in the stomach than CM. Additionally, recent investigations have shown that 28–42 days of CEE or KA supplementation did not increase muscle creatine concentrations more than CM [139,140]. Thus, it appears that CM may be the most effective form of creatine.

Beta-alanine

Beta-alanine (BA) is becoming an increasingly popular supplement among bodybuilders. Once consumed, BA enters the circulation and is up-taken by skeletal muscle where it is used to synthesize carnosine, a pH buffer in muscle that is particularly important during anaerobic exercise such as sprinting or weightlifting [141]. Indeed, consumption of 6.4 g BA daily for four weeks has been shown to increase muscle carnosine levels by 64.2% [142]. Moreover, supplementation with BA for 4–10 weeks has been shown to increase knee extension torque by up to 6% [143], improve workload and time to fatigue during high intensity cardio [144–148], improve muscle resistance to fatigue during strength training [149], increase lean mass by approximately 1 kg [147] and significantly reduce perceptions of fatigue [150]. Additionally, the combination of BA and CM may increase performance of high intensity endurance exercise [151] and has been shown to increase lean mass and decrease body fat percentage more than CM alone [152]. However, not all studies have shown improvements in performance with BA supplementation [143,153,154]. To clarify these discrepancies, Hobson et al. [155] conducted a meta-analysis of 15 studies on BA supplementation and concluded that BA significantly increased exercise capacity and improved exercise performance on 60–240 s ($ES = 0.665$) and >240 s ($ES = 0.368$) exercise bouts.

Although BA appears to improve exercise performance, the long-term safety of BA has only been partially explored. Currently, the only known side effect of BA is unpleasant symptoms of paresthesia reported after consumption of large dosages; however, this can be minimized through consumption of smaller dosages throughout the day [142]. While BA appears to be relatively safe in the short-term, the long-term safety is unknown. In cats, an addition of 5 percent BA to drinking water for 20 weeks has been shown to deplete taurine and result in damage to the brain; however, taurine is an essential amino acid for cats but not for humans and it is unknown if the smaller dosages consumed by humans could result in similar effects [156]. BA may increase exercise performance and increase lean mass in bodybuilders and currently appears to be safe; however, studies are needed to determine the long-term safety of BA consumption.

HMB

Beta-hydroxy-beta-methylbutyrate (HMB) is a metabolite of the amino acid leucine that has been shown to decrease muscle protein catabolism and increase muscle protein synthesis [157,158]. The safety of HMB supplementation has been widely studied and no adverse effects on liver enzymes, kidney function, cholesterol, white blood cells, hemoglobin, or blood glucose have been observed [159–161]. Furthermore, two meta-analyses on HMB supplementation have concluded that HMB is safe and does not result in any major side effects [159,160]. HMB may actually decrease blood pressure, total and LDL cholesterol, especially in hypercholesterolemic individuals.

HMB is particularly effective in catabolic populations such as the elderly and patients with chronic disease [162]. However, studies on the effectiveness of HMB in trained, non-calorically restricted populations have been mixed. Reasons for discrepancies in the results of HMB supplementation studies in healthy populations may be due to many factors including clustering of data in these meta-analysis to include many studies from similar groups, poorly designed, non-periodized training protocols, small sample sizes, and lack of specificity between training and testing conditions [163]. However, as a whole HMB appears to be effective in a majority of studies with longer-duration, more intense, periodized training protocols and may be beneficial to bodybuilders, particularly during planned over-reaching phases of training [164]. While the authors hypothesize that HMB may be effective in periods of increased catabolism, such as during contest preparation, the efficacy of HMB on maintenance of lean mass in dieting athletes has not been investigated in a long-term study. Therefore, future studies are needed to determine the effectiveness of HMB during caloric restriction in healthy, lean, trained athletes.

Branched chain amino acids

Branched chain amino acids (BCAA's) make up 14–18% of amino acids in skeletal muscle proteins and are quite possibly the most widely used supplements among natural bodybuilders [165]. Of the BCAA's, leucine is of particular interest because it has been shown to stimulate protein synthesis to an equal extent as a mixture of all amino acids [166]. However, ingestion of leucine alone can lead to depletion of plasma valine and isoleucine; therefore, all three amino acids need to be consumed to prevent plasma depletion of any one of the BCAA's [167]. Recently, the safe upper limit of leucine was set at 550 mg/kg bodyweight/day in adult men; however, future studies are needed to determine the safe upper limit for both other populations and a mixture of all 3 BCAA's [168].

Numerous acute studies in animals and humans have shown that consumption of either essential amino acids, BCAA's, or leucine either at rest or following exercise

increases skeletal muscle protein synthesis, decreases muscle protein degradation, or both [27,169-172]; however, there are few long-term studies of BCAA supplementation in resistance-trained athletes. Stoppani et al. [173] supplemented trained subjects with either 14 g BCAAs, whey protein, or a carbohydrate placebo for eight weeks during a periodized strength training routine. After training the BCAA group had a 4 kg increase in lean mass, 2% decrease in body fat percentage, and 6 kg increase in bench press 10 repetition maximum. All changes were significant compared to the other groups. However, it should be noted that this data is only available as an abstract and has yet to undergo the rigors of peer-review.

The use of BCAAs between meals may also be beneficial to keep protein synthesis elevated. Recent data from animal models suggest that consumption of BCAAs between meals can overcome the refractory response in protein synthesis that occurs when plasma amino acids are elevated, yet protein synthesis is reduced [174]. However, long-term human studies examining the effects of a diet in which BCAAs are consumed between meals on lean mass and strength have not been done to date. It should also be noted that BCAA metabolism in humans and rodents differ and the results from rodent studies with BCAAs may not translate in human models [175]. Therefore, long-term studies are needed in humans to determine the effectiveness of this practice.

Based on the current evidence, it is clear BCAAs stimulate protein synthesis acutely and one study [173] has indicated that BCAAs may be able to increase lean mass and strength when added to a strength training routine; however, additional long-term studies are needed to determine the effects of BCAAs on lean mass and strength in trained athletes. In addition, studies are needed on the effectiveness of BCAA supplementation in individuals following a vegetarian diet in which consumption of high-quality proteins are low as this may be population that may benefit from BCAA consumption. Furthermore, the effects of BCAA ingestion between meals needs to be further investigated in a long-term human study.

Arginine

“NO supplements” containing arginine are consumed by bodybuilders pre-workout in an attempt to increase blood flow to the muscle during exercise, increase protein synthesis, and improve exercise performance. However, there is little scientific evidence to back these claims. Fahs et al. [176] supplemented healthy young men with 7 g arginine or a placebo prior to exercise and observed no significant change in blood flow following exercise. Additionally, Tang et al. [177] supplemented either 10 g arginine or a placebo prior to exercise and found no significant increase in blood flow or protein synthesis following exercise. Moreover, arginine is a non

essential amino acid and prior work has established that essential amino acids alone stimulate protein synthesis [178]. Based on these findings, it appears that arginine does not significantly increase blood flow or enhance protein synthesis following exercise.

The effects of arginine supplementation on performance are controversial. Approximately one-half of acute and chronic studies on arginine and exercise performance have found significant benefits with arginine supplementation, while the other one-half has found no significant benefits [179]. Moreover, Greer et al. [180] found that arginine supplementation significantly reduced muscular endurance by 2–4 repetitions on chin up and push up endurance tests. Based on these results, the authors of a recent review concluded that arginine supplementation had little impact on exercise performance in healthy individuals [181]. Although the effects of arginine on blood flow, protein synthesis, and exercise performance require further investigation, dosages commonly consumed by athletes are well below the observed safe level of 20 g/d and do not appear to be harmful [182].

Citrulline malate

Citrulline malate (CitM) has recently become a popular supplement among bodybuilders; however, there has been little scientific research in healthy humans with this compound. CitM is hypothesized to improve performance through three mechanisms: 1) citrulline is important part of the urea cycle and may participate in ammonia clearance, 2) malate is a tricarboxylic acid cycle intermediate that may reduce lactic acid accumulation, and 3) citrulline can be converted to arginine; however, as discussed previously, arginine does not appear to have an ergogenic effect in young healthy athletes so it is unlikely CitM exerts an ergogenic effect through this mechanism [179,183].

Supplementation with CitM for 15 days has been shown to increase ATP production by 34% during exercise, increase the rate of phosphocreatine recovery after exercise by 20%, and reduce perceptions of fatigue [184]. Moreover, ingestion of 8 g CitM prior to a chest workout significantly increased repetitions performed by approximately 53% and decreased soreness by 40% at 24 and 48 hours post-workout [183]. Furthermore, Stoppani et al. [173] in an abstract reported a 4 kg increase in lean mass, 2 kg decrease in body fat percentage, and a 6 kg increase in 10 repetition maximum bench press after consumption of a drink containing 14 g BCAA, glutamine, and CitM during workouts for eight weeks; although, it is not clear to what degree CitM contributed to the outcomes observed. However, not all studies have supported ergogenic effects of CitM. Sureda et al. [185] found no significant difference in race time when either 6 g CitM or a placebo were consumed prior to a 137 km cycling stage. Hickner et al. [186] found that treadmill time to

exhaustion was significantly impaired, with the time taken to reach exhaustion occurring on average seven seconds earlier following CitM consumption.

Additionally, the long-term safety of CitM is unknown. Therefore, based on the current literature a decision on the efficacy of CitM cannot be made. Future studies are needed to conclusively determine if CitM is ergogenic and to determine its long term safety.

Glutamine

Glutamine is the most abundant non-essential amino acid in muscle and is commonly consumed as a nutritional supplement. Glutamine supplementation in quantities below 14 g/d appear to be safe in healthy adults [182]; however, at present there is little scientific evidence to support the use of glutamine in healthy athletes [187]. Acutely, glutamine supplementation has not been shown to significantly improve exercise performance [188,189], improve buffering capacity [189], help to maintain immune function or reduce muscle soreness after exercise [187]. Long-term supplementation studies including glutamine in cocktails along with CM, whey protein, BCAA's, and/or CitM have shown 1.5 – 2 kg increases in lean mass and 6 kg increase in 10RM bench press strength [173,190]. However, the role of glutamine in these changes is unclear. Only one study [191] has investigated the effects of glutamine supplementation alone in conjunction with a six week strength training program. No significant differences in muscle size, strength, or muscle protein degradation were observed between groups. Although the previous studies do not support the use of glutamine in bodybuilders during contest preparation, it should be noted that glutamine may be beneficial for gastrointestinal health and peptide uptake in stressed populations [192]; therefore, it may be beneficial in dieting bodybuilders who represent a stressed population. As a whole, the results of previous studies do not support use of glutamine as an ergogenic supplement; however, future studies are needed to determine the role of glutamine on gastrointestinal health and peptide transport in dieting bodybuilders.

Caffeine

Caffeine is perhaps the most common pre-workout stimulant consumed by bodybuilders. Numerous studies support the use of caffeine to improve performance during endurance training [193,194], sprinting [195,196], and strength training [197-199]. However, not all studies support use of caffeine to improve performance in strength training [200,201]. It should be noted that many of the studies that found increases in strength training performance supplemented with larger (5–6 mg/kg) dosages of caffeine. However, this dosage of caffeine is at the end of dosages that are considered safe (6 mg/kg/day) [202]. Additionally, it appears that regular consumption of

caffeine may result in a reduction of ergogenic effects [203]. Therefore, it appears that 5–6 mg/kg caffeine taken prior to exercise is effective in improving exercise performance; however, caffeine use may need to be cycled in order for athletes to obtain the maximum ergogenic effect.

Micronutrients

Several previous studies have observed deficiencies in intakes of micronutrients, such as vitamin D, calcium, zinc, magnesium, and iron, in dieting bodybuilders [3,17,18,204,205]. However, it should be noted that these studies were all published nearly 2 decades ago and that micronutrient deficiencies likely occurred due to elimination of foods or food groups and monotony of food selection [3,205]. Therefore, future studies are needed to determine if these deficiencies would present while eating a variety of foods and using the contest preparation approach described herein. Although the current prevalence of micronutrient deficiencies in competitive bodybuilders is unknown, based on the previous literature, a low-dose micronutrient supplement may be beneficial for natural bodybuilders during contest preparation; however, future studies are needed to verify this recommendation.

Peak week

In an attempt to enhance muscle size and definition by reducing extracellular water content, many bodybuilders engage in fluid, electrolyte, and carbohydrate manipulation in the final days and hours before competing [2,60,206]. The effect of electrolyte manipulation and dehydration on visual appearance has not been studied, however it may be a dangerous practice [207]. Furthermore, dehydration could plausibly degrade appearance considering that extracellular water is not only present in the subcutaneous layer. A significant amount is located in the vascular system. Thus, the common practice of "pumping up" to increase muscle size and definition by increasing blood flow to the muscle with light, repetitive weight lifting prior to stepping on stage [208] could be compromised by dehydration or electrolyte imbalance. Furthermore, dehydration reduces total body hydration. A large percentage of muscle tissue mass is water and dehydration results in decreases in muscle water content [209] and therefore muscle size, which may negatively impact the appearance of muscularity.

In the final days before competing, bodybuilders commonly practice carbohydrate loading similar to endurance athletes in an attempt to raise muscle-glycogen levels and increase muscle size [4,18,60,208]. In the only direct study of this practice, no significant quantitative change in muscle girth was found to occur [208]. However, an isocaloric diet was used, with only a change in

the percentage of carbohydrate contributing to the diet. If total calories had also been increased, greater levels of glycogen might have been stored which could have changed the outcome of this study. Additionally, unlike the subjects in this study bodybuilders prior to carbohydrate loading have reduced glycogen levels from a long calorically restricted diet and it is possible in this state that carbohydrate loading might effect a visual change. Furthermore, bodybuilding performance is measured subjectively, thus analysis of girth alone may not discern subtle visual changes which impact competitive success. Lastly, some bodybuilders alter the amount of carbohydrate loaded based on the visual outcome, increasing the amount if the desired visual change does not occur [60]. Thus, an analysis of a static carbohydrate load may not accurately represent the dynamic nature of actual carbohydrate loading practices.

In fact, in an observational study of competitive bodybuilders in the days before competition who loaded carbohydrates, subjects showed a 4.9% increase in biceps thickness the final day before competition compared to six weeks prior [4]. Although it is unknown if this was caused by increased muscle glycogen, it is unlikely it was due to muscle mass accrual since the final weeks of preparation are often marked by decreases not increases in LBM [6]. Future studies of this practice should include a qualitative analysis of visual changes and analyze the effects of concurrent increases in percentage of carbohydrates as well as total calories.

At this time it is unknown whether dehydration or electrolyte manipulation improves physique appearance. What is known is that these practices are dangerous and have the potential to worsen it. It is unclear if carbohydrate loading has an impact on appearance and if so, how significant the effect is. However, the recommended muscle-sparing practice by some researchers to increase the carbohydrate content of the diet in the final weeks of preparation [6] might achieve any proposed theoretical benefits of carbohydrate loading. If carbohydrate loading is utilized, a trial run before competition once the competitor has reached or nearly reached competition leanness should be attempted to develop an individualized strategy. However, a week spent on a trial run consuming increased carbohydrates and calories may slow fat loss, thus ample time in the diet would be required.

Psychosocial issues

Competitive bodybuilding requires cyclical periods of weight gain and weight loss for competition. In a study by Anderson et al. [207], it was found that 46% of a group of male drug free bodybuilders reported episodes of binge eating after competitions. One third to half reported anxiety, short tempers or anger when preparing for competition and most (81.5%) reported preoccupation with food.

Competitive male bodybuilders exhibit high rates of weight and shape preoccupation, binge eating and bulimia nervosa. However, they exhibit less eating-related and general psychopathology compared to men already diagnosed with bulimia nervosa [210]. Often they are more focused on muscle gain versus fat loss when compared to males with eating disorders [211]. That being said, this may change during preparation for competition when body builders need to reduce body fat levels.

Muscle dysmorphia is higher in male competitive natural bodybuilders than in collegiate football players and non-competitive weight trainers for physique [212]. However, the psychosocial profile of competitive bodybuilders is rather complex. Despite exhibiting greater risk for eating disturbances and a greater psychological investment in their physical appearance, they may have greater levels of physique satisfaction compared to non-competitive weight lifters and athletically active men [213]. Also, male bodybuilders are not a body-image homogenous group when experience is taken into account. Novice bodybuilders show greater levels of dissatisfaction with their muscle size and greater tendencies towards unhealthy and obsessive behavior [214]. Furthermore, the physical effects of semi-starvation in men can approximate the signs and symptoms of eating disorders such as anorexia nervosa and bulimia nervosa [11]. Thus, many of the psychosocial effects and behaviors seen in competitive bodybuilders may be at least partially the result of a prolonged diet and becoming very lean. When these factors are all considered it may indicate that at least in men, competitive bodybuilding drives certain psychosocial behaviors, in addition to those with prior existing behaviors being drawn to the sport.

However this may not be as much the case with female bodybuilders. Walberg [215] when comparing competitive bodybuilders to non-competitive female weight lifters, found that among bodybuilders 42% used to be anorexic, 67% were terrified of becoming fat, and 50% experienced uncontrollable urges to eat. All of these markers were significantly higher in bodybuilders than in non-competitors. Furthermore, it was found that menstrual dysfunction was more common among the bodybuilders. In agreement with this finding, Kleiner et al. [2] reported that 25% of female bodybuilding competitors reported abnormal menstrual cycles.

Competitive bodybuilders are not alone in their risk and disposition towards behaviors that carry health concerns. Elite athletes in aesthetic and weight-class sports as a whole share these risks [216]. In some sports, minimum body fat percentages can be established and minimum hydration levels for weighing in can be set. However, because bodybuilding performance is directly impacted by body fat percentage and not by weight per se, these regulatory changes to the sport are unlikely. Therefore, competitors and trainers should be aware of the potential psychosocial

risks involved with competition. Open and frequent communication on these topics should be practiced and competitors and trainers should be aware of the signs and symptoms of unhealthy behaviors. Early therapeutic intervention by specialists with experience in competitive bodybuilding and eating disorders should occur if disordered eating patterns or psychological distress occurs.

Limitations

The primary limitation of this review is the lack of large-scale long-term studies on competitive natural bodybuilders. To circumvent this, long-term studies on skeletal muscle hypertrophy and body fat loss in athletic dieting human populations were preferentially selected. In the absence of such studies, acute studies and/or animal studies were selected.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

ERH developed the concept for this manuscript and wrote the sections on caloric intake, macronutrients, psychosocial issues and "peak week". AAA wrote the sections on nutrient timing and meal frequency. PJF wrote the abstract, methods, limitations, and the section on dietary supplementation. All authors read and approved the final manuscript.

Author details

¹Sport Performance Research in New Zealand (SPRINZ) at AUT Millennium Institute, AUT University, 17 Antares Place, Mairangi Bay, Auckland 0632, New Zealand. ²California State University, Northridge, CA, USA. ³Division of Nutritional Sciences, University of Illinois, Urbana, IL, USA.

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References

1. Scott BR, Lockie RG, Knight TJ, Clark AC, De Jonge XAK: **A comparison of methods to quantify the in-season training load of professional soccer players.** *Int J Sports Physiol Perform* 2013, **8**:195–202.
2. Kleiner SM, Bazzarre TL, Litchford MD: **Metabolic profiles, diet, and health practices of championship male and female bodybuilders.** *J Am Diet Assoc* 1990, **90**:962–967.
3. Sandoval WM, Heyward VH: **Food selection patterns of bodybuilders.** *Int J Sport Nutr* 1991, **1**:61–68.
4. Bamman MM, Hunter GR, Newton LE, Roney RK, Khaled MA: **Changes in body composition, diet, and strength of bodybuilders during the 12 weeks prior to competition.** *J Sports Med Phys Fitness* 1993, **33**:383–391.
5. Lambert CP, Frank LL, Evans WJ: **Macronutrient considerations for the sport of bodybuilding.** *Sports Med* 2004, **34**:317–327.
6. Maestu J, Eliakim A, Jurimae J, Valter I, Jurimae T: **Anabolic and catabolic hormones and energy balance of the male bodybuilders during the preparation for the competition.** *J Strength Cond Res* 2010, **24**:1074–1081.
7. Hall KD: **What is the required energy deficit per unit weight loss?** *Int J Obes* 2007, **32**:573–576.
8. MacLean PS, Bergouignan A, Cornier M-A, Jackman MR: **Biology's response to dieting: the impetus for weight regain.** *Am J Physiol Regul Integr Comp Physiol* 2011, **301**:R581–R600.
9. Camps SG, Verhoef SP, Westertep KR: **Weight loss, weight maintenance, and adaptive thermogenesis.** *Am J Clin Nutr* 2013, **97**:990–994.
10. Johannsen DL, Knuth ND, Huizenga R, Rood JC, Ravussin E, Hall KD: **Metabolic slowing with massive weight loss despite preservation of fat-free mass.** *J Clin Endocrinol Metab* 2012, **97**:2489–2496.
11. University of Minnesota. *Laboratory of Physiological Hygiene, Keys A: The Biology Of Human Starvation.* Minneapolis: University of Minnesota Press; 1950.
12. Trexler E, Smith-Ryan A, Norton L: **Metabolic adaptation to weight loss: implications for the athlete.** *J Int Soc Sport Nutr* 2014, **11**:7.
13. Garthe I, Raastad T, Refsnes PE, Koivisto A, Sundgot-Borgen J: **Effect of two different weight-loss rates on body composition and strength and power-related performance in elite athletes.** *Int J Sport Nutr Exerc Metab* 2011, **21**:97–104.
14. Forbes GB: **Body fat content influences the body composition response to nutrition and exercise.** *Ann N Y Acad Sci* 2000, **904**:359–365.
15. Hall KD: **Body fat and fat-free mass inter-relationships: Forbes's theory revisited.** *Br J Nutr* 2007, **97**:1059–1063.
16. Mero AA, Huovinen H, Matintupa O, Hulmi JJ, Puurtinen R, Hohtari H, Karila T: **Moderate energy restriction with high protein diet results in healthier intermenstrual changes in women.** *J Int Soc Sports Nutr* 2010, **7**:4.
17. Sandoval WM, Heyward VH, Lyons TM: **Comparison of body composition, exercise and nutritional profiles of female and male bodybuilders at competition.** *J Sports Med Phys Fitness* 1989, **29**:63–70.
18. Walberg-Rankin J, Edmonds CE, Gwazdauskas FC: **Diet and weight changes of female bodybuilders before and after competition.** *Int J Sport Nutr* 1993, **3**:87–102.
19. Withers RT, Noell CJ, Whittingham NO, Chatterton BE, Schultz CG, Keeves JP: **Body composition changes in elite male bodybuilders during preparation for competition.** *Aust J Sci Med Sport* 1997, **29**:11–16.
20. van der Ploeg GE, Brooks AG, Withers RT, Dollman J, Leaney F, Chatterton BE: **Body composition changes in female bodybuilders during preparation for competition.** *Eur J Clin Nutr* 2001, **55**:268–277.
21. Newton LE, Hunter GR, Bamman M, Roney RK: **Changes in psychological state and self-reported diet during various phases of training in competitive bodybuilders.** *J Strength Cond Res* 1993, **7**:153–158.
22. Butterfield GE: **Whole-body protein utilization in humans.** *Med Sci Sports Exerc* 1987, **19**:S157–S165.
23. Lemon PW: **Beyond the zone: protein needs of active individuals.** *J Am Coll Nutr* 2000, **19**:S135–S215.
24. Phillips SM: **Dietary protein for athletes: from requirements to metabolic advantage.** *Appl Physiol Nutr Metab* 2006, **31**:647–654.
25. Phillips SM, Moore DR, Tang JE: **A critical examination of dietary protein requirements, benefits, and excesses in athletes.** *Int J Sport Nutr Exerc Metab* 2007, **17**(Suppl):S58–S76.
26. Slater G, Phillips SM: **Nutrition guidelines for strength sports: sprinting, weightlifting, throwing events, and bodybuilding.** *J Sports Sci* 2011, **29**:S67–S77.
27. Tipton KD, Wolfe RR: **Protein and amino acids for athletes.** *J Sports Sci* 2004, **22**:65–79.
28. Phillips SM, Van Loon LJ: **Dietary protein for athletes: from requirements to optimum adaptation.** *J Sports Sci* 2011, **29**(Suppl 1):S29–S38.
29. Mettler S, Mitchell N, Tipton KD: **Increased protein intake reduces lean body mass loss during weight loss in athletes.** *Med Sci Sports Exerc* 2010, **42**:326–337.
30. Millward DJ: **Macronutrient intakes as determinants of dietary protein and amino acid adequacy.** *J Nutr* 2004, **134**:1588S–1596S.
31. Stiegler P, Cunliffe A: **The role of diet and exercise for the maintenance of fat-free mass and resting metabolic rate during weight loss.** *Sports Med* 2006, **36**:239–262.
32. Walberg JL, Leidy MK, Sturgill DJ, Hinkle DE, Ritchey SJ, Sebolt DR: **Macronutrient content of a hypocaloric diet affects nitrogen retention and muscle function in weight lifters.** *Int J Sports Med* 1988, **9**:261–266.
33. Helms ER, Zinn C, Rowlands DS, Brown SR: **A systematic review of dietary protein during caloric restriction in resistance trained lean athletes: a case for higher intakes.** *Int J Sport Nutr Exerc Metab* 2013, Epub ahead of print.
34. Elibi M, Stubbs RJ, Henry CJ: **Differences in fat, carbohydrate, and protein metabolism between lean and obese subjects undergoing total starvation.** *Obes Res* 1999, **7**:597–604.
35. Phillips SM: **Protein requirements and supplementation in strength sports.** *Nutrition* 2004, **20**:689–695.
36. Tarnopolsky MA: **Building muscle: nutrition to maximize bulk and strength adaptations to resistance exercise training.** *Eur J Sport Sci* 2008, **8**:67–76.
37. Tipton KD: **Protein for adaptations to exercise training.** *Eur J Sport Sci* 2008, **8**:107–118.
38. Wilson J, Wilson GJ: **Contemporary issues in protein requirements and consumption for resistance trained athletes.** *J Int Soc Sports Nutr* 2006, **3**:7–27.

39. Celejowa I, Homa M: **Food intake, nitrogen and energy balance in Polish weight lifters, during a training camp.** *Nutr Metab* 1970, **12**:259–274.
40. Pasiakos SM, Cao JJ, Margolis LM, Sauter ER, Whigham LD, McClung JP, Rood JC, Carbone JW, Combs GF Jr, Young AJ: **Effects of high-protein diets on fat-free mass and muscle protein synthesis following weight loss: a randomized controlled trial.** *FASEB J* 2013, **27**:3837–3847.
41. Leveritt M, Abernethy PJ: **Effects of carbohydrate restriction on strength performance.** *J Strength Cond Res* 1999, **13**:52–57.
42. Haff GG, Koch AJ, Potteiger JA, Kuphal KE, Magee LM, Green SB, Jakicic JJ: **Carbohydrate supplementation attenuates muscle glycogen loss during acute bouts of resistance exercise.** *Int J Sport Nutr Exerc Metab* 2000, **10**:326–339.
43. MacDougall JD, Ray S, Sale DG, McCartney N, Lee P, Garner S: **Muscle substrate utilization and lactate production.** *Can J Appl Physiol* 1999, **24**:209–215.
44. Layman DK, Boileau RA, Erickson DJ, Painter JE, Shiue H, Sather C, Christou DD: **A reduced ratio of dietary carbohydrate to protein improves body composition and blood lipid profiles during weight loss in adult women.** *J Nutr* 2003, **133**:411–417.
45. Layman DK, Baum JI: **Dietary protein impact on glycemic control during weight loss.** *J Nutr* 2004, **134**:968S–973S.
46. Halton TL, Hu FB: **The effects of high protein diets on thermogenesis, satiety and weight loss: a critical review.** *J Am Coll Nutr* 2004, **23**:373–385.
47. Veldhorst M, Smeets A, Soenen S, Hochstenbach-Waelen A, Hursel R, Diepvens K, Lejeune M, Luscombe-Marsh N, Westerterp-Plantenga M: **Protein-induced satiety: effects and mechanisms of different proteins.** *Physiol Behav* 2008, **94**:300–307.
48. Westerterp-Plantenga MS: **Protein intake and energy balance.** *Regul Pept* 2008, **149**:67–69.
49. Smeets AJ, Soenen S, Luscombe-Marsh ND, Ueland O, Westerterp-Plantenga MS: **Energy expenditure, satiety, and plasma ghrelin, glucagon-like peptide 1, and peptide tyrosine-tyrosine concentrations following a single high-protein lunch.** *J Nutr* 2008, **138**:698–702.
50. Cook CM, Haub MD: **Low-carbohydrate diets and performance.** *Curr Sports Med Rep* 2007, **6**:225–229.
51. Volek JS, Kraemer WJ, Bush JA, Incledon T, Boetes M: **Testosterone and cortisol in relationship to dietary nutrients and resistance exercise.** *J Appl Physiol* 1997, **82**:49–54.
52. Sallinen J, Pakarinen A, Ahtiainen J, Kraemer WJ, Volek JS, Häkkinen K: **Relationship between diet and serum anabolic hormone responses to heavy-resistance exercise in men.** *Int J Sports Med* 2004, **25**:627–633.
53. Härmäläinen EK, Adlercreutz H, Puska P, Pietinen P: **Decrease of serum total and free testosterone during a low-fat high-fibre diet.** *J Steroid Biochem* 1983, **18**:369–370.
54. Dorgan JF, Judd JT, Longcope C, Brown C, Schatzkin A, Clevidence BA, Campbell WS, Nair PP, Franz C, Kahle L, Taylor PR: **Effects of dietary fat and fiber on plasma and urine androgens and estrogens in men: a controlled feeding study.** *Am J Clin Nutr* 1996, **64**:850–855.
55. Härmäläinen EK, Adlercreutz H, Puska P, Pietinen P: **Diet and serum sex hormones in healthy men.** *J Steroid Biochem* 1984, **20**:459–464.
56. Suryanarayana BV, Kent JR, Meister L, Parlow AF: **Pituitary-gonadal axis during prolonged total starvation in obese men.** *Am J Clin Nutr* 1969, **22**:767–770.
57. Rossow LM, Fukuda DH, Fahs CA, Loenneke JP, Stout JR: **Natural bodybuilding competition preparation and recovery: a 12-month case study.** *Int J Sports Physiol Perform* 2013, **8**:582–592.
58. Loucks AB, Verdun M, Heath EM: **Low energy availability, not stress of exercise, alters LH pulsatility in exercising women.** *J Appl Physiol* 1998, **84**:37–46.
59. Bird SP: **Strength nutrition: maximizing your anabolic potential.** *Strength Cond J* 2010, **32**:80–86.
60. Shephard RJ: **Electrolyte manipulation in female body-builders.** *Br J Sports Med* 1994, **28**:60–61.
61. Too D, Wakayama EJ, Locati LL, Landwer GE: **Effect of a precompetition bodybuilding diet and training regimen on body composition and blood chemistry.** *J Sports Med Phys Fitness* 1998, **38**:245–252.
62. Sawyer JC, Wood RJ, Davidson PW, Collins SM, Matthews TD, Gregory SM, Paolone VJ: **Effects of a short-term carbohydrate-restricted diet on strength and power performance.** *J Strength Cond Res* 2013, **27**:2255–2262.
63. Soenen S, Bonomi AG, Lemmens SGT, Scholte J, Thijssen MAMA, van Berkum F, Westerterp-Plantenga MS: **Relatively high-protein or 'low-carb' energy-restricted diets for body weight loss and body weight maintenance?** *Physiol Behav* 2012, **107**:374–380.
64. Paoli A, Grimaldi K, D'Agostino D, Cenci L, Moro T, Bianco A, Palma A: **Ketogenic diet does not affect strength performance in elite artistic gymnasts.** *J Int Soc Sports Nutr* 2012, **9**:34.
65. Essen-Gustavsson B, Tesch PA: **Glycogen and triglyceride utilization in relation to muscle metabolic characteristics in men performing heavy-resistance exercise.** *Eur J Appl Physiol* 1990, **61**:5–10.
66. Goedecke JH, Gibson ASC, Grobler L, Collins M, Noakes TD, Lambert EV: **Determinants of the variability in respiratory exchange ratio at rest and during exercise in trained athletes.** *Am J Physiol Endocrinol Metab* 2000, **279**:E1325–E1334.
67. Cormier MA, Donahoo WT, Pereira R, Gurevich I, Westergren R, Enerback S, Eckel PJ, Goalstone ML, Hill JO, Eckel RH, Draznin B: **Insulin sensitivity determines the effectiveness of dietary macronutrient composition on weight loss in obese women.** *Obes Res* 2005, **13**:703–709.
68. Pendergast DR, Leddy JJ, Venkatraman JT: **A perspective on fat intake in athletes.** *J Am Coll Nutr* 2000, **19**:345–350.
69. Turocy PS, DePalma BF, Horswill CA, Laquale KM, Martin TJ, Perry AC, Somova MJ, Utter AC: **National athletic trainers' association position statement: safe weight loss and maintenance practices in sport and exercise.** *J Athl Train* 2011, **46**:322–336.
70. Ivy JL, Katz AL, Cutler CL, Sherman WM, Coyle EF: **Muscle glycogen synthesis after exercise: effect of time of carbohydrate ingestion.** *J Appl Physiol* 1988, **64**:1480–1485.
71. Jentjens R, Jeukendrup A: **Determinants of post-exercise glycogen synthesis during short-term recovery.** *Sports Med* 2003, **33**:117–144.
72. Robergs RA, Pearson DR, Costill DL, Fink WJ, Pascoe DD, Benedict MA, Lambert CP, Zachweija JJ: **Muscle glycogenolysis during differing intensities of weight-resistance exercise.** *J Appl Physiol* 1991, **70**:1700–1706.
73. Roy BD, Tarnopolsky MA: **Influence of differing macronutrient intakes on muscle glycogen resynthesis after resistance exercise.** *J Appl Physiol* 1998, **84**:890–896.
74. Fujita S, Dreyer HC, Drummond MJ, Glynn EL, Volpi E, Rasmussen BB: **Essential amino acid and carbohydrate ingestion before resistance exercise does not enhance postexercise muscle protein synthesis.** *J Appl Physiol* 2009, **106**:1730–1739.
75. Baty JJ, Hwang H, Ding Z, Bernard JR, Wang B, Kwon B, Ivy JL: **The effect of a carbohydrate and protein supplement on resistance exercise performance, hormonal response, and muscle damage.** *J Strength Cond Res* 2007, **21**:321–329.
76. Tipton KD, Elliott TA, Cree MG, Aarsland AA, Sanford AP, Wolfe RR: **Stimulation of net muscle protein synthesis by whey protein ingestion before and after exercise.** *Am J Physiol Endocrinol Metab* 2007, **292**:E71–E76.
77. Bird SP, Tarpenning KM, Marino FE: **Liquid carbohydrate/essential amino acid ingestion during a short-term bout of resistance exercise suppresses myofibrillar protein degradation.** *Metabolism* 2006, **55**:570–577.
78. Levenhagen DK, Gresham JD, Carlson MG, Maron DJ, Borel MJ, Flakoll PJ: **Postexercise nutrient intake timing in humans is critical to recovery of leg glucose and protein homeostasis.** *Am J Physiol Endocrinol Metab* 2001, **280**:E982–E993.
79. Tipton KD, Rasmussen BB, Miller SL, Wolf SE, Owens-Stovall SK, Petrini BE, Wolfe RR: **Timing of amino acid-carbohydrate ingestion alters anabolic response of muscle to resistance exercise.** *Am J Physiol Endocrinol Metab* 2001, **281**:E197–E206.
80. Cribb PJ, Hayes A: **Effects of supplement timing and resistance exercise on skeletal muscle hypertrophy.** *Med Sci Sports Exerc* 2006, **38**:1918–1925.
81. Esmarck B, Andersen JL, Olsen S, Richter EA, Mizuno M, Kjaer M: **Timing of postexercise protein intake is important for muscle hypertrophy with resistance training in elderly humans.** *J Physiol* 2001, **535**:301–311.
82. Burk A, Timpmann S, Medjainen L, Vahi M, Oopik V: **Time-divided ingestion pattern of casein-based protein supplement stimulates an increase in fat-free body mass during resistance training in young untrained men.** *Nutr Res* 2009, **29**:405–413.
83. Hoffman JR, Ratamess NA, Tranchina CP, Rashti SL, Kang J, Faigenbaum AD: **Effect of protein-supplement timing on strength, power, and body-composition changes in resistance-trained men.** *Int J Sport Nutr Exerc Metab* 2009, **19**:172–185.
84. Wycherley TP, Noakes M, Clifton PM, Cleanthous X, Keogh JB, Brinkworth GD: **Timing of protein ingestion relative to resistance exercise training**

- does not influence body composition, energy expenditure, glycaemic control or cardiometabolic risk factors in a hypocaloric, high protein diet in patients with type 2 diabetes. *Diabetes Obes Metab* 2010, **12**:1097–1105.
85. Weisgarber KD, Candow DG, Vogt ES: **Whey protein before and during resistance exercise has no effect on muscle mass and strength in untrained young adults.** *Int J Sport Nutr Exerc Metab* 2012, **22**:463–469.
86. Willoughby DS, Stout JR, Wilborn CD: **Effects of resistance training and protein plus amino acid supplementation on muscle anabolism, mass, and strength.** *Amino Acids* 2007, **32**:467–477.
87. Hulmi JJ, Kovanen V, Selanne H, Kraemer WJ, Hakkinen K, Mero AA: **Acute and long-term effects of resistance exercise with or without protein ingestion on muscle hypertrophy and gene expression.** *Amino Acids* 2009, **37**:297–308.
88. Verdijk LB, Jonkers RA, Gleeson BG, Beelen M, Meijer K, Savelberg HH, Wodzig WK, Dendale P, van Loon LJ: **Protein supplementation before and after exercise does not further augment skeletal muscle hypertrophy after resistance training in elderly men.** *Am J Clin Nutr* 2009, **89**:608–616.
89. Erskine RM, Fletcher G, Hanson B, Folland JP: **Whey protein does not enhance the adaptations to elbow flexor resistance training.** *Med Sci Sports Exerc* 2012, **44**:1791–1800.
90. Burd NA, West DW, Moore DR, Atherton PJ, Staples AW, Prior T, Tang JE, Rennie MJ, Baker SK, Phillips SM: **Enhanced amino acid sensitivity of myofibrillar protein synthesis persists for up to 24 h after resistance exercise in young men.** *J Nutr* 2011, **141**:568–573.
91. Deldicque L, De Bock K, Maris M, Ramaekers M, Nielens H, Francaux M, Hespel P: **Increased p70s6k phosphorylation during intake of a protein-carbohydrate drink following resistance exercise in the fasted state.** *Eur J Appl Physiol* 2010, **108**:791–800.
92. Moore DR, Robinson MJ, Fry JL, Tang JE, Glover EI, Wilkinson SB, Prior T, Tarnopolsky MA, Phillips SM: **Ingested protein dose response of muscle and albumin protein synthesis after resistance exercise in young men.** *Am J Clin Nutr* 2009, **89**:161–168.
93. Yang Y, Breen L, Burd NA, Hector AJ, Churchward-Venne TA, Josse AR, Tarnopolsky MA, Phillips SM: **Resistance exercise enhances myofibrillar protein synthesis with graded intakes of whey protein in older men.** *Br J Nutr* 2012, **108**:1–9.
94. Hamer HM, Wall BT, Kiskini A, de Lange A, Groen BB, Bakker JA, Gijzen AP, Verdijk LB, van Loon LJ: **Carbohydrate co-ingestion with protein does not further augment post-prandial muscle protein accretion in older men.** *Nutr Metab (Lond)* 2013, **10**:15.
95. Staples AW, Burd NA, West DW, Currie KD, Atherton PJ, Moore DR, Rennie MJ, Macdonald MJ, Baker SK, Phillips SM: **Carbohydrate does not augment exercise-induced protein accretion versus protein alone.** *Med Sci Sports Exerc* 2011, **43**:1154–1161.
96. Greenhaff PL, Karagounis LG, Peirce N, Simpson EJ, Hazell M, Layfield R, Wackerhage H, Smith K, Atherton P, Selby A, Rennie MJ: **Disassociation between the effects of amino acids and insulin on signaling, ubiquitin ligases, and protein turnover in human muscle.** *Am J Physiol Endocrinol Metab* 2008, **295**:E595–E604.
97. Koopman R, Beelen M, Stellingwerff T, Pennings B, Saris WH, Kies AK, Kuipers H, van Loon LJ: **Coingestion of carbohydrate with protein does not further augment postexercise muscle protein synthesis.** *Am J Physiol Endocrinol Metab* 2007, **293**:E833–E842.
98. Kerksick C, Harvey T, Stout J, Campbell B, Wilborn C, Kreider R, Kalman D, Ziegenfuss T, Lopez H, Landis J, Ivy JL, Antonio J: **International Society of Sports Nutrition position stand: nutrient timing.** *J Int Soc Sports Nutr* 2008, **5**:17.
99. Aragon AA, Schoenfeld BJ: **Nutrient timing revisited: is there a post-exercise anabolic window?** *J Int Soc Sports Nutr* 2013, **10**:5.
100. Taylor MA, Garrow JS: **Compared with nibbling, neither gorging nor a morning fast affect short-term energy balance in obese patients in a chamber calorimeter.** *Int J Obes Relat Metab Disord* 2001, **25**:519–528.
101. de Venne WP V-v, Westertep KR: **Influence of the feeding frequency on nutrient utilization in man: consequences for energy metabolism.** *Eur J Clin Nutr* 1991, **45**:161–169.
102. Farshchi HR, Taylor MA, Macdonald IA: **Decreased thermic effect of food after an irregular compared with a regular meal pattern in healthy lean women.** *Int J Obes Relat Metab Disord* 2004, **28**:653–660.
103. Farshchi HR, Taylor MA, Macdonald IA: **Regular meal frequency creates more appropriate insulin sensitivity and lipid profiles compared with irregular meal frequency in healthy lean women.** *Eur J Clin Nutr* 2004, **58**:1071–1077.
104. Harvie MN, Pegington M, Mattson MP, Frystyk J, Dillon B, Evans G, Cuzick J, Jebb SA, Martin B, Cutler RG, Son TG, Maudsley S, Carlson OD, Egan JM, Flyvbjerg A, Howell A: **The effects of intermittent or continuous energy restriction on weight loss and metabolic disease risk markers: a randomized trial in young overweight women.** *Int J Obes* 2011, **35**:714–727.
105. Soeters MR, Lammers NM, Dubbelhuis PF, Ackermans M, Jonkers-Schuitema CF, Fliers E, Sauerwein HP, Aerts JM, Serlie MJ: **Intermittent fasting does not affect whole-body glucose, lipid, or protein metabolism.** *Am J Clin Nutr* 2009, **90**:1244–1251.
106. Arnal MA, Mosoni L, Boirie Y, Houlier ML, Morin L, Verdier E, Ritz P, Antoine JM, Prugnaud J, Beaufriere B, Mirand PP: **Protein feeding pattern does not affect protein retention in young women.** *J Nutr* 2000, **130**:1700–1704.
107. Arnal MA, Mosoni L, Boirie Y, Houlier ML, Morin L, Verdier E, Ritz P, Antoine JM, Prugnaud J, Beaufriere B, Mirand PP: **Protein pulse feeding improves protein retention in elderly women.** *Am J Clin Nutr* 1999, **69**:1202–1208.
108. La Bounty PM, Campbell BI, Wilson J, Galvan E, Berardi J, Kleiner SM, Kreider RB, Stout JR, Ziegenfuss T, Spano M, Smith A, Antonio J: **International Society of Sports Nutrition position stand: meal frequency.** *J Int Soc Sports Nutr* 2011, **8**:4.
109. Varady KA: **Intermittent versus daily calorie restriction: which diet regimen is more effective for weight loss?** *Obes Rev* 2011, **12**:e593–e601.
110. Bony-Westphal A, Later W, Hitze B, Sato T, Kossel E, Gluer CC, Heller M, Muller MJ: **Accuracy of bioelectrical impedance consumer devices for measurement of body composition in comparison to whole body magnetic resonance imaging and dual X-ray absorptiometry.** *Obes Facts* 2008, **1**:319–324.
111. Pateyjohns IR, Brinkworth GD, Buckley JD, Noakes M, Clifton PM: **Comparison of three bioelectrical impedance methods with DXA in overweight and obese men.** *Obesity (Silver Spring)* 2006, **14**:2064–2070.
112. Neovius M, Hemmingsson E, Freyschuss B, Udden J: **Bioelectrical impedance underestimates total and truncal fatness in abdominally obese women.** *Obesity (Silver Spring)* 2006, **14**:1731–1738.
113. Stote KS, Baer DJ, Spears K, Paul DR, Harris GK, Rumlper WW, Strycula P, Najjar SS, Ferrucci L, Ingram DK, Longo DL, Mattson MP: **A controlled trial of reduced meal frequency without caloric restriction in healthy, normal-weight, middle-aged adults.** *Am J Clin Nutr* 2007, **85**:981–988.
114. Iwao S, Mori K, Sato Y: **Effects of meal frequency on body composition during weight control in boxers.** *Scand J Med Sci Sports* 1996, **6**:265–272.
115. Benardot D, Martin DE, Thompson WR, Roman SB: **Between-meal energy intake effects on body composition, performance, and total caloric consumption in athletes.** *Med Sci Sports Exerc* 2005, **37**:S339.
116. Norton LE, Wilson GJ: **Optimal protein intake to maximize muscle protein synthesis: examinations of optimal meal protein intake.** *Agro Food Industry Hi-Tech* 2009, **20**:54–57.
117. Bohe J, Low JF, Wolfe RR, Rennie MJ: **Latency and duration of stimulation of human muscle protein synthesis during continuous infusion of amino acids.** *J Physiol* 2001, **532**:575–579.
118. Atherton PJ, Etheridge T, Watt PW, Wilkinson D, Selby A, Rankin D, Smith K, Rennie MJ: **Muscle full effect after oral protein: time-dependent concordance and discordance between human muscle protein synthesis and mTORC1 signaling.** *Am J Clin Nutr* 2010, **92**:1080–1088.
119. Munsters MJ, Saris WH: **Effects of meal frequency on metabolic profiles and substrate partitioning in lean healthy males.** *PLoS One* 2012, **7**:e38632.
120. Holmstrup M, Owens CM, Fairchild TJ, Kanaley JA: **Effect of meal frequency on glucose and insulin excursions over the course of a day.** *Eur e-J Clin Nutr Metab* 2010, **5**:277–280.
121. Leidy HJ, Armstrong CL, Tang M, Mattes RD, Campbell WW: **The influence of higher protein intake and greater eating frequency on appetite control in overweight and obese men.** *Obesity (Silver Spring)* 2010, **18**:1725–1732.
122. Arciero PJ, Ormsbee MJ, Gentile CL, Nindl BC, Brestoff JR, Ruby M: **Increased protein intake and meal frequency reduces abdominal fat during energy balance and energy deficit.** *Obesity (Silver Spring)* 2013, **21**:1357–1366.
123. Adechian S, Balage M, Remond D, Migne C, Quignard-Boulange A, Marset-Baglieri A, Rousset S, Boirie Y, Gaudichon C, Dardevet D, Mosoni L: **Protein feeding pattern, casein feeding or milk soluble protein feeding did not change the evolution of body composition during a short-term weight loss program.** *Am J Physiol Endocrinol Metab* 2012, **303**:E973–E982.

124. Moore DR, Areta J, Coffey VG, Stellingwerff T, Phillips SM, Burke LM, Cleroux M, Godin JP, Hawley JA: **Daytime pattern of post-exercise protein intake affects whole-body protein turnover in resistance-trained males.** *Nutr Metab (Lond)* 2012, **9**:91.
125. Areta JL, Burke LM, Ross ML, Camera DM, West DW, Broad EM, Jeacocke NA, Moore DR, Stellingwerff T, Phillips SM, Hawley JA, Coffey VG: **Timing and distribution of protein ingestion during prolonged recovery from resistance exercise alters myofibrillar protein synthesis.** *J Physiol* 2013, **591**:2319–2331.
126. **OCB/NANBF/IFPA Drug Testing Guidelines.** [http://www.thenaturalmusclenetwork.com/OCB/forms/DrugTestingGuidelines.pdf]
127. Campbell B, Kreider RB, Ziegenfuss T, La Bounty P, Roberts M, Burke D, Landis J, Lopez H, Antonio J: **International Society of Sports Nutrition position stand: protein and exercise.** *J Int Soc Sports Nutr* 2007, **4**:8.
128. Buford TW, Kreider RB, Stout JR, Greenwood M, Campbell B, Spano M, Ziegenfuss T, Lopez H, Landis J, Antonio J: **International Society of Sports Nutrition position stand: creatine supplementation and exercise.** *J Int Soc Sports Nutr* 2007, **4**:6.
129. Kim H, Kim C, Carpentier A, Poortmans J: **Studies on the safety of creatine supplementation.** *Amino Acids* 2011, **40**:1409–1418.
130. Becque MD, Lochmann JD, Melrose DR: **Effects of oral creatine supplementation on muscular strength and body composition.** *Med Sci Sports Exerc* 2000, **32**:654–658.
131. Volek JS, Duncan ND, Mazzetti SA, Staron RS, Putukian M, Gomez AL, Pearson DR, Fink WJ, Kraemer WJ: **Performance and muscle fiber adaptations to creatine supplementation and heavy resistance training.** *Med Sci Sports Exerc* 1999, **31**:1147–1156.
132. Willoughby DS, Rosene J: **Effects of oral creatine and resistance training on myosin heavy chain expression.** *Med Sci Sports Exerc* 2001, **33**:1674–1681.
133. Vandenberghe K, Goris M, Van Hecke P, Van Leemputte M, Vangerven L, Hespel P: **Long-term creatine intake is beneficial to muscle performance during resistance training.** *J Appl Physiol* 1997, **83**:2055–2063.
134. Stone MH, Sanborn K, Smith LL, O'Bryant HS, Hoke T, Utter AC, Johnson RL, Boros R, Hruby J, Pierce KC, Stone ME, Garner B: **Effects of in-season (5 weeks) creatine and pyruvate supplementation on anaerobic performance and body composition in American football players.** *Int J Sport Nutr* 1999, **9**:146–165.
135. Persky AM, Brazeau GA: **Clinical pharmacology of the dietary supplement creatine monohydrate.** *Pharmacol Rev* 2001, **53**:161–176.
136. Hultman E, Soderlund K, Timmons JA, Cederblad G, Greenhaff PL: **Muscle creatine loading in men.** *J Appl Physiol* 1996, **81**:232–237.
137. Tallon MJ, Child R: **Kre-alkalyn supplementation has no beneficial effect on creatine-to-creatinine conversion rates.** In *Book Kre-alkalyn supplementation has no beneficial effect on creatine-to-creatinine conversion rates.* City: 2007.
138. Child RT MJ: **Creatine ethyl ester rapidly degrades to creatinine in stomach acid.** In *Book Creatine ethyl ester rapidly degrades to creatinine in stomach acid*; 2007.
139. Spillane M, Schoch R, Cooke M, Harvey T, Greenwood M, Kreider R, Willoughby DS: **The effects of creatine ethyl ester supplementation combined with heavy resistance training on body composition, muscle performance, and serum and muscle creatine levels.** *J Int Soc Sports Nutr* 2009, **6**:6.
140. Jagim AR, Oliver JM, Sanchez A, Galvan E, Fluckey J, Riechman S, Greenwood M, Kelly K, Meininger C, Rasmussen C, Kreider RB: **A buffered form of creatine does not promote greater changes in muscle creatine content, body composition, or training adaptations than creatine monohydrate.** *J Int Soc Sports Nutr* 2012, **9**:43.
141. Artioli GG, Gualano B, Smith A, Stout J, Lancha AH Jr: **Role of beta-alanine supplementation on muscle carnosine and exercise performance.** *Med Sci Sports Exerc* 2010, **42**:1162–1173.
142. Harris RC, Tallon MJ, Dunnett M, Boobis L, Coakley J, Kim HJ, Fallowfield JL, Hill CA, Sale C, Wise JA: **The absorption of orally supplied beta-alanine and its effect on muscle carnosine synthesis in human vastus lateralis.** *Amino Acids* 2006, **30**:279–289.
143. Derave W, Ozdemir MS, Harris RC, Pottier A, Reyngoudt H, Koppo K, Wise JA, Achten E: **Beta-Alanine supplementation augments muscle carnosine content and attenuates fatigue during repeated isokinetic contraction bouts in trained sprinters.** *J Appl Physiol* 2007, **103**:1736–1743.
144. Hill CA, Harris RC, Kim HJ, Harris BD, Sale C, Boobis LH, Kim CK, Wise JA: **Influence of beta-alanine supplementation on skeletal muscle carnosine concentrations and high intensity cycling capacity.** *Amino Acids* 2007, **32**:225–233.
145. Van Thienen R, Van Proeyen K, Vanden Eynde P, Puype J, Lefere T, Hespel P: **Beta-alanine improves sprint performance in endurance cycling.** *Med Sci Sports Exerc* 2009, **41**:898–903.
146. Sale C, Saunders B, Hudson S, Wise JA, Harris RC, Sunderland CD: **Effect of beta-alanine plus sodium bicarbonate on high-intensity cycling capacity.** *Med Sci Sports Exerc* 2011, **43**:1972–1978.
147. Smith AE, Walter AA, Graef JL, Kendall KL, Moon JR, Lockwood CM, Fukuda DH, Beck TW, Cramer JT, Stout JR: **Effects of beta-alanine supplementation and high-intensity interval training on endurance performance and body composition in men; a double-blind trial.** *J Int Soc Sports Nutr* 2009, **6**:5.
148. Stout JR, Cramer JT, Zoeller RF, Torok D, Costa P, Hoffman JR, Harris RC, O'Kroy J: **Effects of beta-alanine supplementation on the onset of neuromuscular fatigue and ventilatory threshold in women.** *Amino Acids* 2007, **32**:381–386.
149. Hoffman J, Ratamess NA, Ross R, Kang J, Magreli J, Neese K, Faigenbaum AD, Wise JA: **Beta-alanine and the hormonal response to exercise.** *Int J Sports Med* 2008, **29**:952–958.
150. Hoffman JR, Ratamess NA, Faigenbaum AD, Ross R, Kang J, Stout JR, Wise JA: **Short-duration beta-alanine supplementation increases training volume and reduces subjective feelings of fatigue in college football players.** *Nutr Res* 2008, **28**:31–35.
151. Zoeller RF, Stout JR, O'Kroy JA, Torok DJ, Mielke M: **Effects of 28 days of beta-alanine and creatine monohydrate supplementation on aerobic power, ventilatory and lactate thresholds, and time to exhaustion.** *Amino Acids* 2007, **33**:505–510.
152. Hoffman J, Ratamess N, Kang J, Mangine G, Faigenbaum A, Stout J: **Effect of creatine and beta-alanine supplementation on performance and endocrine responses in strength/power athletes.** *Int J Sport Nutr Exerc Metab* 2006, **16**:430–446.
153. Kendrick IP, Harris RC, Kim HJ, Kim CK, Dang VH, Lam TQ, Bui TT, Smith M, Wise JA: **The effects of 10 weeks of resistance training combined with beta-alanine supplementation on whole body strength, force production, muscular endurance and body composition.** *Amino Acids* 2008, **34**:547–554.
154. Sweeney KM, Wright GA, Glenn Brice A, Doberstein ST: **The effect of beta-alanine supplementation on power performance during repeated sprint activity.** *J Strength Cond Res* 2010, **24**:79–87.
155. Hobson RM, Saunders B, Ball G, Harris RC, Sale C: **Effects of beta-alanine supplementation on exercise performance: a meta-analysis.** *Amino Acids* 2012, **43**:25–37.
156. Lu P, Xu W, Sturman JA: **Dietary beta-alanine results in taurine depletion and cerebellar damage in adult cats.** *J Neurosci Res* 1996, **43**:112–119.
157. Smith HJ, Mukerji P, Tisdale MJ: **Attenuation of proteasome-induced proteolysis in skeletal muscle by [beta]-hydroxy-[beta]-methylbutyrate in cancer-induced muscle loss.** *Cancer Res* 2005, **65**:277–283.
158. Eley HL, Russell ST, Baxter JH, Mukerji P, Tisdale MJ: **Signaling pathways initiated by beta-hydroxy-beta-methylbutyrate to attenuate the depression of protein synthesis in skeletal muscle in response to cachectic stimuli.** *Am J Physiol Endocrinol Metab* 2007, **293**:E923–E931.
159. Rathmacher JA, Nissen S, Panton L, Clark RH, Eubanks May P, Barber AE, D'Olimpio J, Abumrad NN: **Supplementation with a combination of beta-hydroxy-beta-methylbutyrate (HMB), arginine, and glutamine is safe and could improve hematological parameters.** *JPEN J Parenter Enteral Nutr* 2004, **28**:65–75.
160. Nissen S, Sharp RL, Panton L, Vukovich M, Trappe S, Fuller JC Jr: **Beta-hydroxy-beta-methylbutyrate (HMB) supplementation in humans is safe and may decrease cardiovascular risk factors.** *J Nutr* 2000, **130**:1937–1945.
161. Gallagher PM, Carrithers JA, Godard MP, Schulze KE, Trappe SW: **Beta-hydroxy-beta-methylbutyrate ingestion, part II: effects on hematology, hepatic and renal function.** *Med Sci Sports Exerc* 2000, **32**:2116–2119.
162. Fitschen PJ, Wilson GJ, Wilson JM, Wilund KR: **Efficacy of beta-hydroxy-beta-methylbutyrate supplementation in elderly and clinical populations.** *Nutrition* 2013, **29**:29–36.
163. Wilson GJ, Wilson JM, Manninen AH: **Effects of beta-hydroxy-beta-methylbutyrate (HMB) on exercise performance and body composition across varying levels of age, sex, and training experience: a review.** *Nutr Metab (Lond)* 2008, **5**:1.

164. Wilson J, Fitschen P, Campbell B, Wilson G, Zanchi N, Taylor L, Wilborn C, Kalman D, Stout J, Hoffman J, Ziegenfuss T, Lopez H, Kreider R, Smith-Ryan A, Antonio J: **International Society of Sports Nutrition Position Stand: beta-hydroxy-beta-methylbutyrate (HMB).** *J Int Soc Sports Nutr* 2013, **10**:6.
165. Shimomura Y, Yamamoto Y, Bajotto G, Sato J, Murakami T, Shimomura N, Kobayashi H, Mawatari K: **Nutraceutical effects of branched-chain amino acids on skeletal muscle.** *J Nutr* 2006, **136**:529S–532S.
166. Garlick PJ, Grant I: **Amino acid infusion increases the sensitivity of muscle protein synthesis in vivo to insulin. Effect of branched-chain amino acids.** *Biochem J* 1988, **254**:579–584.
167. Balage M, Dardevet D: **Long-term effects of leucine supplementation on body composition.** *Curr Opin Clin Nutr Metab Care* 2010, **13**:265–270.
168. Pencharz PB, Elango R, Ball RO: **Determination of the tolerable upper intake level of leucine in adult men.** *J Nutr* 2012, **142**:2220S–2224S.
169. Biolo G, Tipton KD, Klein S, Wolfe RR: **An abundant supply of amino acids enhances the metabolic effect of exercise on muscle protein.** *Am J Physiol* 1997, **273**:E122–E129.
170. Tipton KD, Ferrando AA, Phillips SM, Doyle D Jr, Wolfe RR: **Postexercise net protein synthesis in human muscle from orally administered amino acids.** *Am J Physiol* 1999, **276**:E628–E634.
171. Louard RJ, Barrett EJ, Gelfand RA: **Effect of infused branched-chain amino acids on muscle and whole-body amino acid metabolism in man.** *Clin Sci* 1990, **79**:457–466.
172. Borsheim E, Tipton KD, Wolf SE, Wolfe RR: **Essential amino acids and muscle protein recovery from resistance exercise.** *Am J Physiol Endocrinol Metab* 2002, **283**:E648–E657.
173. Stoppini J, Scheett T, Pena J, Rudolph C, Charlebois D: **Consuming a supplement containing branched-chain amino acids during a resistance-training program increases lean mass, muscle strength, and fat loss.** *J Int Soc Sports Nutr* 2009, **6**:P1.
174. Wilson GJ, Layman DK, Moulton CJ, Norton LE, Anthony TG, Proud CG, Rupassara SI, Garlick PJ: **Leucine or carbohydrate supplementation reduces AMPK and eEF2 phosphorylation and extends postprandial muscle protein synthesis in rats.** *Am J Physiol Endocrinol Metab* 2011, **301**:E1236–E1242.
175. Suryawan A, Hawes JW, Harris RA, Shimomura Y, Jenkins AE, Hutson SM: **A molecular model of human branched-chain amino acid metabolism.** *Am J Clin Nutr* 1998, **68**:72–81.
176. Fahs CA, Heffernan KS, Fernhall B: **Hemodynamic and vascular response to resistance exercise with L-arginine.** *Med Sci Sports Exerc* 2009, **41**:773–779.
177. Tang JE, Lysecki PJ, Manolagas JJ, MacDonald MJ, Tarnopolsky MA, Phillips SM: **Bolus arginine supplementation affects neither muscle blood flow nor muscle protein synthesis in young men at rest or after resistance exercise.** *J Nutr* 2011, **141**:195–200.
178. Volpi E, Kobayashi H, Sheffield-Moore M, Mittendorfer B, Wolfe RR: **Essential amino acids are primarily responsible for the amino acid stimulation of muscle protein anabolism in healthy elderly adults.** *Am J Clin Nutr* 2003, **78**:250–258.
179. Alvares TS, Meirelles CM, Bhamhani YN, Paschoalin VM, Gomes PS: **L-Arginine as a potential ergogenic aid in healthy subjects.** *Sports Med* 2011, **41**:233–248.
180. Greer BK, Jones BT: **Acute arginine supplementation fails to improve muscle endurance or affect blood pressure responses to resistance training.** *J Strength Cond Res* 2011, **25**:1789–1794.
181. McConeill GK: **Effects of L-arginine supplementation on exercise metabolism.** *Curr Opin Clin Nutr Metab Care* 2007, **10**:46–51.
182. Shao A, Hathcock JN: **Risk assessment for the amino acids taurine, L-glutamine and L-arginine.** *Regul Toxicol Pharmacol* 2008, **50**:376–399.
183. Perez-Guisado J, Jakeman PM: **Citrulline malate enhances athletic anaerobic performance and relieves muscle soreness.** *J Strength Cond Res* 2010, **24**:1215–1222.
184. Bendahan D, Mattei JP, Ghattas B, Confort-Gouny S, Le Guern ME, Cozzzone PJ: **Citrulline/malate promotes aerobic energy production in human exercising muscle.** *Br J Sports Med* 2002, **36**:282–289.
185. Sureda A, Cordova A, Ferrer MD, Perez G, Tur JA, Pons A: **L-citrulline-malate influence over branched chain amino acid utilization during exercise.** *Eur J Appl Physiol* 2010, **110**:341–351.
186. Hickner RC, Tanner CJ, Evans CA, Clark PD, Haddock A, Fortune C, Geddis H, Waugh W, McCammon M: **L-citrulline reduces time to exhaustion and insulin response to a graded exercise test.** *Med Sci Sports Exerc* 2006, **38**:660–666.
187. Gleeson M: **Dosing and efficacy of glutamine supplementation in human exercise and sport training.** *J Nutr* 2008, **138**:2045S–2049S.
188. Antonio J, Sanders MS, Kalman D, Woodgate D, Street C: **The effects of high-dose glutamine ingestion on weightlifting performance.** *J Strength Cond Res* 2002, **16**:157–160.
189. Haub MD, Potteiger JA, Nau KL, Webster MJ, Zebas CJ: **Acute L-glutamine ingestion does not improve maximal effort exercise.** *J Sports Med Phys Fitness* 1998, **38**:240–244.
190. Colker CM, Swain MA, Fabrucini B, Shi Q, Kalman DS: **Effects of supplemental protein on body composition and muscular strength in healthy athletic male adults.** *Curr Ther Res* 2000, **61**:19–28.
191. Candow DG, Chillbeck PD, Burke DG, Davison KS, Smith-Palmer T: **Effect of glutamine supplementation combined with resistance training in young adults.** *Eur J Appl Physiol* 2001, **86**:142–149.
192. Camilleri M, Madsen K, Spiller R, Van Meerveld BG, Verne GN: **Intestinal barrier function in health and gastrointestinal disease.** *Neurogastroenterol Motil* 2012, **24**:503–512.
193. Ivy JL, Kammer L, Ding Z, Wang B, Bernard JR, Liao YH, Hwang J: **Improved cycling time-trial performance after ingestion of a caffeine energy drink.** *Int J Sport Nutr Exerc Metab* 2009, **19**:61–78.
194. McNaughton LR, Lovell RJ, Siegler J, Midgley AW, Moore L, Bentley DJ: **The effects of caffeine ingestion on time trial cycling performance.** *Int J Sports Physiol Perform* 2008, **3**:157–163.
195. Carr A, Dawson B, Schneiker K, Goodman C, Lay B: **Effect of caffeine supplementation on repeated sprint running performance.** *J Sports Med Phys Fitness* 2008, **48**:472–478.
196. Glaister M, Howatson G, Abraham CS, Lockey RA, Goodwin JE, Foley P, McInnes G: **Caffeine supplementation and multiple sprint running performance.** *Med Sci Sports Exerc* 2008, **40**:1835–1840.
197. Green JM, Wickwire PJ, McLester JR, Gendle S, Hudson G, Pritchett RC, Laurent CM: **Effects of caffeine on repetitions to failure and ratings of perceived exertion during resistance training.** *Int J Sports Physiol Perform* 2007, **2**:250–259.
198. Woolf K, Bidwell WK, Carlson AG: **The effect of caffeine as an ergogenic aid in anaerobic exercise.** *Int J Sport Nutr Exerc Metab* 2008, **18**:412–429.
199. Duncan MJ, Oxford SW: **The effect of caffeine ingestion on mood state and bench press performance to failure.** *J Strength Cond Res* 2011, **25**:178–185.
200. Williams AD, Cribb PJ, Cooke MB, Hayes A: **The effect of ephedra and caffeine on maximal strength and power in resistance-trained athletes.** *J Strength Cond Res* 2008, **22**:464–470.
201. Hendrix CR, Housh TJ, Mielke M, Zuniga JM, Camic CL, Johnson GO, Schmidt RJ, Housh DJ: **Acute effects of a caffeine-containing supplement on bench press and leg extension strength and time to exhaustion during cycle ergometry.** *J Strength Cond Res* 2010, **24**:859–865.
202. Nawrot P, Jordan S, Eastwood J, Rotstein J, Hugenholtz A, Feeley M: **Effects of caffeine on human health.** *Food Addit Contam* 2003, **20**:1–30.
203. Tarnopolsky MA, Atkinson SA, MacDougall JD, Sale DG, Sutton JR: **Physiological responses to caffeine during endurance running in habitual caffeine users.** *Med Sci Sports Exerc* 1989, **21**:418–424.
204. Bazzarre TL, Kleiner SM, Litchford MD: **Nutrient intake, body fat, and lipid profiles of competitive male and female bodybuilders.** *J Am Coll Nutr* 1990, **9**:136–142.
205. Kleiner SM, Bazzarre TL, Ainsworth BE: **Nutritional status of nationally ranked elite bodybuilders.** *Int J Sport Nutr* 1994, **4**:54–69.
206. Hickson JF Jr, Johnson TE, Lee W, Sidor RJ: **Nutrition and the precontest preparations of a male bodybuilder.** *J Am Diet Assoc* 1990, **90**:264–267.
207. Andersen RE, Barlett SJ, Morgan GD, Brownell KD: **Weight loss, psychological, and nutritional patterns in competitive male bodybuilders.** *Int J Eat Disord* 1995, **18**:49–57.
208. Balon TW, Horowitz JF, Fitzsimmons KM: **Effects of carbohydrate loading and weight-lifting on muscle girth.** *Int J Sport Nutr* 1992, **2**:328–334.
209. Costill DL, Cote R, Fink W: **Muscle water and electrolytes following varied levels of dehydration in man.** *J Appl Physiol* 1976, **40**:6–11.
210. Goldfield GS, Blouin AG, Woodside DB: **Body image, binge eating, and bulimia nervosa in male bodybuilders.** *Can J Psychiatry* 2006, **51**:160–168.
211. Mangweth B, Pope HG Jr, Kemmler G, Ebenbichler C, Hausmann A, De Col C, Kreutner B, Kinzl J, Biebl W: **Body image and psychopathology in male bodybuilders.** *Psychother Psychosom* 2001, **70**:38–43.

212. Baghurst T, Lirgg C: Characteristics of muscle dysmorphia in male football, weight training, and competitive natural and non-natural bodybuilding samples. *Body Image* 2009, **6**:221–227.
213. Pickett TC, Lewis RJ, Cash TF: Men, muscles, and body image: comparisons of competitive bodybuilders, weight trainers, and athletically active controls. *Br J Sports Med* 2005, **39**:217–222. discussion 217–222.
214. Jankauskiene R, Kardelis K, Pajaujiene S: Muscle size satisfaction and predisposition for a health harmful practice in bodybuilders and recreational gymnasium users. *Medicina (Kaunas)* 2007, **43**:338–346.
215. Walberg JL, Johnston CS: Menstrual function and eating behavior in female recreational weight lifters and competitive body builders. *Med Sci Sports Exerc* 1991, **23**:30–36.
216. Sundgot-Borgen J, Garthe I: Elite athletes in aesthetic and Olympic weight-class sports and the challenge of body weight and body compositions. *J Sports Sci* 2011, **29**(Suppl 1):S101–S114.

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