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Dietary Supplements and the Promotion of Muscle Growth with Resistance Exercise

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Contents

Abstract . . . 97
1. Dietary Strategies for Enhancing Lean Tissue Accretion . . . 98
 1.1 Overfeeding . . . 98
 1.2 Pre- and Post-Exercise Meals . . . 99
2. Nutrients Purported to Affect Lean Tissue Accretion . . . 100
 2.1 Protein and Selected Amino Acids . . . 100
  2.1.1 Protein . . . 100
  2.1.2 Glutamine . . . 100
  2.1.3 Branched-Chain Amino Acids . . . 101
  2.1.4 Creatine and Nutritional Formulations Containing Creatine . . . 101
  2.1.5 Leucine and Calcium β-Hydroxy β-Methylbutyrate . . . 102
 2.2 Chromium . . . 104
 2.3 Vanadyl Sulfate . . . 105
 2.4 Boron . . . 106
 2.5 Prasterone and Androstenedione . . . 106
3. Conclusions and Implications . . . 107

Abstract

Nutritional strategies of overfeeding, ingesting carbohydrate/protein before and after exercise, and dietary supplementation of various nutrients [e.g. protein, glutamine, branched-chain amino acid, creatine, leucine, β-hydroxy β-methylbutyrate (β-HMB), chromium, vanadyl sulfate, boron, prasterone (dehydroepiandrosterone [DHEA]) and androstenedione] have been purported to promote gains in fat-free mass during resistance training.

Most studies indicate that chromium, vanadyl sulfate and boron supplementation do not affect muscle growth. However, there is evidence that ingesting carbohydrate/protein prior to exercise may reduce catabolism during exercise and that ingesting carbohydrate/protein following resistance-exercise may promote a more anabolic hormonal profile. Furthermore, glutamine, creatine, leucine, and calcium β-HMB may affect protein synthesis.

Creatine and calcium β-HMB supplementation during resistance training have been reported to increase fat-free mass in athletic and nonathletic populations. Prasterone supplementation has been reported to increase testosterone and fat-free mass in nontrained populations. However, results are equivocal, studies have yet to be conducted on athletes, and prasterone is considered a banned substance by some athletic organisations.

This paper discusses rationale and effectiveness of these nutritional strategies in promoting lean tissue accretion during resistance training.

One of the primary goals of resistance training is to promote gains in muscle mass.[1] Chronic resistance training typically promotes gains in fat-free mass ranging between 0 to 1kg per month.[1-3] However, gains in fat-free mass during resistance training vary among individuals.[2,3] In this regard, whereas some athletes may experience gains in fat-free mass, other athletes observe little change.[2,3] For this reason, both athletes and coaches have searched for ways to augment usual training-induced alterations in fat-free mass primarily through experimentation with nutritional supplements and/or pharmacological agents.[4]

While it is clear that pharmacological agents such as anabolic-androgenic steroids and growth hormones may promote muscle growth,[5-9] there are significant medical, ethical and legal concerns.[10] Consequently, athletes have relied to a greater degree on nutritional strategies designed to promote muscle growth. This has resulted in an explosion in the development, marketing and research of nutritional supplements purported to promote lean tissue accretion. Although there is evidence suggesting that dietary manipulation and/or supplementation of some nutrients may enhance gains in fat-free mass during resistance training, many of the nutrients marketed to athletes have few scientific data to support their claims of effectiveness. The purpose of this review is to examine the rationale and effectiveness of some of the most popular dietary supplements purported to promote muscle growth during resistance training and to provide insight regarding recommendations for athletes.

1. Dietary Strategies for Enhancing Lean Tissue Accretion

1.1 Overfeeding

The most common nutritional strategy to promote weight gain and muscle growth is overfeeding.[2,11,12] This is typically accomplished by adding meals, carbohydrate-rich snacks, and/or ingesting high calorie carbohydrate/protein weight-gain supplements in order to increase energy intake by 500 to 2000 Cal/day. While this method has been shown to be an effective strategy in promoting weight gain,[2,11,12] typically only 30 to 40% of the weight gain is fat-free mass.

For example, Forbes and associates[11] investigated the effects of 3 weeks of overfeeding (900 to 1800 Cal/day) on body composition alterations. Study participants consumed a diet consisting of 15% protein, 45% carbohydrate and 40% fat, and maintained a light activity level. Body mass increased by an average of 4.4kg (3.5 to 5.9kg) and fat-free mass was increased by 1.7kg (0 to 5.1kg) representing 38% of the total weight gain. Similar findings have been observed with carbohydrate overfeeding. Welle and associates[12] evaluated the effects of carbohydrate supplementation (400 g/day) for 10 days on fat-free mass alterations in 11 men whose baseline diet was 2600 Cal/day. Carbohydrate overfeeding promoted a positive nitrogen balance and a 2.9kg increase in total body mass. However, only 33% of the weight gain was fat-free mass.

Although overfeeding is an effective method of promoting weight gain, most of the weight gained is fat which may not be a desirable body composition alteration for athletes. Nevertheless, resistance-trained athletes often use this method to ‘bulk up’ and then diet in an attempt to lose the unwanted fat gained. This is despite the fact that when people lose weight on calorie-restricted diets approximately 50% of the weight loss is fat-free mass.[2] Consequently, in my view, this nutritional strategy should not be recommended to athletes as a means of promoting muscle growth unless the athlete is severely underweight and/or the added fat mass gained will not compromise performance.

1.2 Pre- and Post-Exercise Meals

Another nutritional strategy employed by athletes to promote muscle growth is ingesting carbohydrate, or carbohydrate and protein, before and/or after periods of exercise. These strategies have been based on reports indicating that ingesting carbohydrate/protein before exercise may increase insulin levels thereby decreasing exercise-induced catabolism,[13,14] and that ingesting carbohydrate or carbohydrate/protein following exercise may hasten recovery,[14] promote a more anabolic hormonal profile,[15] decrease myofibrillar protein breakdown and urea nitrogen excretion,[16] and enhance glycogen resynthesis.[17-19]

For example, Chandler and colleagues[15] investigated the effects of ingesting carbohydrate and/or protein supplements after a standardised resistance-training workout on hormonal profiles. Participants consumed a water control or isocaloric amounts of carbohydrate (1.5 g/kg), protein (1.38 g/kg) or carbohydrate and protein (1.06 g/kg carbohydrate, 0.41 g/kg protein) immediately and 2 hours after the workout. Insulin levels were increased to a greater degree in the carbohydrate and the carbohydrate/protein groups, and ingesting carbohydrate/protein after exercise promoted a modest but significant increase in growth hormone levels. These findings suggest that ingesting carbohydrate and protein following resistance training may promote a more favourable hormonal environment to promote muscle growth.

Cade and associates[14] investigated the effects of carbohydrate and protein supplementation following swim training in 20 male and 20 female intercollegiate swimmers. Swimmers were randomised into 1 of 5 supplementation groups while maintaining their regular training diets. One group consumed water during exercise and was not administered a supplement after training sessions. A second group consumed water during periods of exercise and was supplemented with 80g of sucrose immediately after each training session. The third group consumed water during exercise and then 80g of sucrose with 15g of milk protein after exercise. The remaining 2 groups consumed a 6% glucose-electrolyte solution during swim training and then either 80g of sucrose or 80g of sucrose with 15g of milk protein after training. The researchers found that regardless of consuming water or glucose-electrolyte solution during exercise, creatine kinase levels were lower in the groups receiving the sucrose-protein supplement after exercise. In addition, creatine kinase levels returned to baseline sooner in the group receiving sucrose-protein after exercise (3 hours) compared with carbohydrate supplementation alone (8 hours). These findings suggest that ingestion of carbohydrate and protein following exercise may hasten the rate of muscle recovery during intense training.

Finally, Roy and co-workers[16] investigated the effects on markers of protein metabolism of ingesting carbohydrate (1 g/kg immediately and 1 hour after exercise) following resistance training. Participants performed 8 sets of about 10 repetitions at 85% 1 repetition maximum (RM) of unilateral knee extension exercise followed by ingesting placebo or carbohydrate during recovery. Carbohydrate supplementation resulted in significantly greater increases in blood glucose levels during the first hour and insulin levels during the first 2 hours of recovery. In addition, fractional muscle protein synthetic rate in the carbohydrate supplemented group was nonsignificantly higher (36%) in the exercise compared with the non-exercise leg. Furthermore, urinary excretion of 3-methylhistidine and urea nitrogen were significantly lower in the carbohydrate supplemented group. The researchers concluded that carbohydrate supplementation following resistance training can decrease myofibrillar protein degradation and urea nitrogen excretion thereby promoting a more positive nitrogen balance.

Ingesting carbohydrate and protein before and/or after exercise has been reported to lessen catabolism during running,[13] hasten recovery following swim training,[14] modestly increase growth hormone levels following resistance training,[15] and enhance glycogen resynthesis following endurance[17,18] and resistance training.[16,19] Consequently, following these nutritional strategies during training may lead to greater gains in fat-free mass. However, although there is sound scientific rationale to recommend these nutritional strategies for athletes, this hypothesis has not been evaluated during long term training periods. Additional research is necessary to evaluate the effects of meal timing and composition on hormonal responses to resistance-exercise and body composition alterations during training.

2. Nutrients Purported to Affect Lean Tissue Accretion

2.1 Protein and Selected Amino Acids

2.1.1 Protein

It is a commonly held belief amongst resistance-trained athletes that in order to promote muscle growth, the diet must be supplemented with large amounts of protein. While studies[20,21] indicate that athletes involved in intense training may have greater protein needs than non-exercising counterparts (i.e. 1.3 to 2 *vs* 0.8 to 1 g/kg/day), most athletes who eat enough to maintain energy balance achieve these recommendations.[20-22] Furthermore, increasing dietary intake of protein above that necessary to maintain nitrogen balance does not appear to promote lean tissue accretion.[20,21]

For example, Tarnopolsky and colleagues[20] investigated the effects of dietary intake of protein on strength and body composition in untrained and trained men in a randomised, double-blind crossover study. Six sedentary and 7 resistance-trained athletes ingested 0.86, 1.4, and 2.4 g/kg/day of protein for 13 days separated by an 8 day washout period. Resistance-trained athletes had a greater daily requirement for protein (1.4 g/kg/day). However, increased protein intake did not affect changes in fat-free mass in either group. These findings suggest that resistance-trained athletes may need between 1.7 to 1.8 g/kg/day of protein in order to ensure nitrogen balance but that ingesting protein above this level does not promote muscle growth.

Similarly, Lemon and co-workers[21] investigated the effects of protein supplementation on body composition and strength alterations in a group of novice bodybuilders. In a repeated measures crossover design, 12 male bodybuilders randomly ingested 1.35 or 2.62 g/kg/day of protein while consuming a 3500 Cal/day diet. Participants trained for 4 weeks, observed a 7 day washout period, and then repeated the experiment with the alternate protein intake. There were no significant differences observed between groups in gains in body mass, muscle mass (determined by density, creatinine excretion, and computerised axial tomography), or strength.

Therefore, although it is important for athletes to ingest an adequate amount of protein in order to maintain a positive nitrogen balance during training (i.e. 1.3 to 2 g/kg/day), and ingesting carbohydrate and protein after resistance-exercise may promote a more favourable anabolic hormonal profile,[15] consuming additional amounts of protein does not appear to promote muscle growth. Furthermore, most resistance-trained athletes ingest a sufficient amount of dietary protein in their usual diet to accommodate the increased protein needs observed.

2.1.2 Glutamine

Glutamine is a common ingredient currently found in many of the weight-gain supplements marketed to athletes. Glutamine is an amino acid which has been suggested to promote muscle growth and decrease exercise-induced immunosuppression. These contentions are based on animal and human studies that investigated the effect of glutamine on protein synthesis,[23,24] cell volume[25] and glycogen synthesis.[26] Studies also suggest that intense exercise may decrease glutamine levels[27,28] and that this decrease may contribute to exercise-induced immunosuppression in overtrained athletes.[27-29]

In analysis of this literature, it appears that glutamine is an important metabolic nutrient affecting protein synthesis,[23,24] possibly by increasing cell volume and osmotic pressure.[25] Furthermore, glutamine availability directly affects lymphocytic function.[27-29] Branched-chain amino acid (4 to 16g) and/or glutamine supplementation (4 to 12g) has been shown to increase glutamine levels.[22,29] Consequently, there is some evidence to support glutamine supplementation, in that it may promote muscle growth[23,24] and/or prevent upper respiratory tract infections among athletes.[22,27-29] However, long term studies investigating the effects of glutamine supplementation on protein synthesis, body composition, and the incidence of upper respiratory tract infections during resistance training have yet to be conducted. Consequently, although basic research is promising, additional research is necessary.

2.1.3 Branched-Chain Amino Acids

Branched-chain amino acid supplementation has been reported to decrease exercise-induced protein degradation and/or serum muscle enzyme efflux,[30-32] possibly by promoting an anticatabolic hormonal profile.[13,15] Theoretically, branched chain amino acid supplementation during intense training may help minimise protein degradation and thereby lead to greater gains in fat-free mass.[22,29,33,34]

In support of this contention, Carli and associates[13] reported that addition of 10g of branched chain amino acid to a carbohydrate/protein drink promoted a more anabolic response to intense running compared with ingesting the carbohydrate/ protein supplement without branched chain amino acid. Moreover, Coombes and McNaughton[31] reported that branched chain amino acid supplementation (12 g/day for 14 days) prior to performing a 2-hour period of endurance cycling at 70% of maximal oxygen uptake, significantly decreased post-exercise creatine kinase and lactate dehydrogenase (LDH) enzyme efflux. This suggests that branched chain amino acid supplementation may reduce exercise-induced muscle damage. Mourier et al.[33] found that branched chain amino acid supplementation during 19 days of calorie restriction in wrestlers promoted a greater reduction in percent body fat while maintaining fat-free mass to a greater degree compared with athletes on hypocaloric control, hypocaloric low protein, and hypocaloric high protein diets. Finally, we reported that branched chain amino acid supplementation with carbohydrate during 25 weeks of swim training promoted a greater increase in fat-free mass and reduction in percent body fat compared with carbohydrate supplementation alone.[22,23]

Although results of these studies support contentions that branched chain amino acid supplementation may affect protein degradation and/or muscle mass, none of these studies evaluated the effects of branched chain amino acid supplementation on body composition alterations during resistance training. Consequently, additional research is necessary to determine whether branched chain amino acid supplementation prior to and/or following resistance-exercise promotes muscle growth.

2.1.4 Creatine and Nutritional Formulations Containing Creatine

Dietary supplementation of creatine and nutritional formulations containing creatine have become the most popular nutritional strategy employed by resistance-trained athletes to promote gains in strength and fat-free mass.[35] The rationale for this is that creatine supplementation (20 to 25 g/day for 4 to 7 days then 2 to 25 g/day) has been reported to increase total body mass,[36-42] fat-free mass,[38-40,42-47] single-effort and/or repetitive sprint capacity,[39-41,43,44,48-55] strength and/or power,[38,39,43,47-49,56] and work performed during sets of maximal effort muscle contractions.[37,39,40,42,44,50,53,56] It has been suggested that the increased body mass is due to creatine stimulated water retention,[53] protein synthesis,[38,54-59] and/or an improved quality of training leading to greater gains in strength and fat-free mass.[39-40,42-44,46,47] Gains in total body mass and fat-free mass following creatine supplementation and nutritional formulations containing creatine are typically 0.8 to 3kg greater than matched-paired control participants, depending on the duration and amount of supplementation.

For example, Earnest and colleagues[39] reported that 28 days of creatine supplementation (20 g/day) during resistance training significantly increased total body mass by 1.7kg ($p < 0.05$) and that gains in hydrostatically determined fat-free mass accounted for 1.5kg of the total body mass gain ($p = 0.054$). Moreover, Vandenburghe and associates[47] reported that women consuming creatine (20 g/day for 4 days followed by 5 g/day for 66 days) during resistance training observed significantly greater gains in fat-free mass compared with a placebo group. These gains were maintained during a subsequent 70-day detraining period with continued supplementation (5 g/day). In addition, the gains in fat-free mass were maintained 28 days after cessation of supplementation despite muscle phosphocreatine levels returning toward pre-supplementation values.

Studies from our laboratory investigating the effects of ingesting commercially available supplements containing 15 to 25 g/day of creatine during 4 to 5 weeks of resistance training indicate that gains in fat-free mass were 1.1 to 2.3kg greater (1- to 2-fold) than gains observed when participants ingested near isocaloric amounts of carbohydrate,[40,45,46] carbohydrate/protein,[42,60] or even a higher calorie carbohydrate/protein supplement containing chromium, as chromium picolinate, and boron.[42] Whether the gains in fat-free mass observed in these studies were due to creatine and/or a synergist action with other nutrients contained in these formulations remains to be determined. Nevertheless, these data suggest that supplementing the diet with creatine, and/or these specific creatine-containing formulations, is an effective means of promoting gains in strength and fat-free mass during resistance training. For a more detailed review on the effects of creatine supplementation on exercise and body composition, refer to 2 recent comprehensive reviews.[61,62]

2.1.5 Leucine and Calcium β-Hydroxy β-Methylbutyrate

Leucine and metabolites of leucine such as α-ketoisocaproate have been reported to inhibit protein degradation particularly during periods of increased proteolysis.[63,64] It has been suggested that the anticatabolic effects of leucine and α-ketoisocaproate are regulated by the leucine metabolite β-hydroxy β-methylbutyrate (β-HMB). Animal studies indicate that β-HMB is synthesised from α-ketoisocaproate almost entirely as a byproduct of leucine metabolism and that approximately 5% of oxidised leucine is converted to β-HMB.[65,66] Furthermore, that adding β-HMB to dietary feed improved carcass quality in sows[65] and steers.[66] Based on these findings, it has been hypothesised that supplementing the diet with leucine and/or β-HMB may inhibit protein degradation during periods of increased proteolysis such as resistance training.

In support of this contention, intravenous leucine infusion has been reported to decrease protein degradation in humans suggesting that leucine may serve as a regulator of protein metabolism.[63] Moreover, Nissen and colleagues[64] reported significantly greater gains in fat-free mass and strength in untrained men and women[67] initiating resistance training when administered calcium β-HMB 1.5 or 3 g/day for 3 to 4 weeks. The gains in fat-free mass were approximately 0.4 to 0.7kg greater than in the placebo groups. These researchers also reported[64] that 3 g/day of calcium β-HMB supplementation ingested with a carbohydrate/protein meal replacement powder significantly increased fat-free mass (≈2.7kg in the first 3 to 4 weeks) during 7 weeks of off-season college football resistance training compared with participants ingesting an isocaloric amount of orange juice. Calcium β-HMB supplementation was also associated with less serum creatine kinase and LDH efflux as well as urinary 3-methylhistidine excretion suggesting that participants ingesting β-HMB experienced less catabolism during training.[64] Finally, Vukovich and coworkers[68] reported that 8 weeks of calcium β-HMB supplementation (3 g/day) significantly increased fat-free mass (–0.58 *vs* 1.5%), reduced fat mass (0.27 *vs* –2.2%), and promoted greater gains in upper and lower extremity 1RM strength in a group of elderly men and women (≈70 years) initiating training.

Although additional research is necessary, these findings suggest that supplementing the diet with calcium β-HMB 1.5 to 3 g/day may enhance training induced changes in fat-free mass and strength in untrained participants initiating training[64,67,68] as well as in well-trained participants.[64]

However, results from 2 studies conducted in our laboratory do not entirely support these findings.[40,45,69,70] In the first study, 52 college football players undergoing off-season resistance/agility training (≈8 hours/week) were administered in a double-blind and randomised manner either a carbohydrate/electrolyte placebo, the placebo with calcium β-HMB 3 g/day, the placebo with creatine monohydrate 15.5 g/day, or the placebo with β-HMB 3 g/day and creatine monophosphate 15.5 g/day for 28 days. Fasting blood samples, dual energy x-ray absorptiometer (DEXA) determined body composition, maximal effort isotonic bench press, squat and power clean repetition tests, and a cycle ergometer sprint test (12 × 6-second sprints with a 30-second rest recovery), were obtained before and after supplementation. Gains in fat-free mass in the placebo/β-HMB group (1.4 ± 0.3kg) were not significantly different to changes observed in the placebo group (1.3 ± 0.3kg) and gains in fat-free mass in the placebo/creatine group (2.4 ± 0.4kg) and the placebo/β-HMB/creatine group (2.6 ± 0.5kg) were significantly greater than the placebo and placebo/β-HMB groups. There was no evidence that calcium β-HMB supplementation reduced muscle and liver enzyme efflux. Furthermore, calcium β-HMB supplementation had minimal effects on repetitive sprint performance and lifting volume. These findings suggest that calcium β-HMB during intense training has limited value.

In our second study, 40 experienced resistance-trained athletes were matched according to training volume (7.3 ± 1 hours/week) and fat-free mass, and assigned to supplement their diet for 28 days with a fortified carbohydrate/protein powder (84 g/day carbohydrate, 75 g/day protein, 3 g/day fat) containing calcium β-HMB 0, 3 or 6 g/day. Fasting blood samples, DEXA determined body composition, and 1RM leg press and bench press were obtained before and after the supplementation period. Changes in creatine kinase levels in the 6 g/day group tended to be lower ($p = 0.09$) than changes in the 0 g/day group (82 ± 71; –24 ± 28; –101 ± 92IU for the 0, 3 and 6 g/day groups, respectively). However, no significant differences were observed between groups in LDH, urea nitrogen or creatinine levels, or in the ratio of urea nitrogen to creatinine. In addition, no statistically significant differences were observed in changes in fat-free mass (0.28 ± 0.4, 0.69 ± 0.4, 1.04 ± 0.3kg; $p = 0.44$) or combined gains in bench press and leg press 1RM strength (1.8 ± 3, 4.1 ± 2, 4.6 ± 2kg; $p = 0.68$). Consequently, although changes observed in fat-free mass and strength were similar to values previously reported in untrained individuals initiating training,[64,65,67,68] ingesting calcium β-HMB 3 and 6 g/day with a fortified carbohydrate/protein supplement during resistance training did not promote statistically significant increases in fat-free mass or strength.

Although additional research is necessary, it appears that calcium β-HMB supplementation may help reduce catabolism and affect lean tissue accretion in untrained individuals initiating resistance training. However, it is less clear whether calcium β-HMB promotes muscle growth in well-trained athletes involved in intense resistance training. In the one study that reported significant gains in fat-free mass in resistance-trained athletes,[64] calcium β-HMB was added to a popular carbohydrate/protein vitamin/mineral fortified meal replacement supplement and compared with participants ingesting isocaloric amounts of orange juice. Consequently, it is unclear whether calcium β-HMB supplementation and/or some combination of nutrients was responsible for the gains in fat-free mass observed.

Data from our laboratory suggest that supplementation with calcium β-HMB 3 and 6 g/day has limited effects on alterations in fat-free mass during resistance training in well-trained athletes. Furthermore, that other nutritional interventions such as dietary supplementation with creatine or nutritional formulations containing creatine[40,42,45,46,60,69,70] may be more effective in promoting muscle growth than calcium β-HMB. Consequently, our current recommendations in counselling resistance-trained athletes about calcium β-HMB supplementation is that:

(i) it is unclear whether calcium β-HMB promotes muscle growth and/or gains in strength in well-trained athletes;

(ii) there is evidence that supplementation of creatine and/or creatine-containing supplements may be more effective; and

(iii) if they want to try this nutritional strategy that they ingest calcium β-HMB with a carbohydrate/protein meal vitamin/mineral fortified replacement powder or in addition to creatine and/or creatine-containing supplements.

2.2 Chromium

Chromium is an essential biologically active trace mineral primarily involved as a component of glucose tolerance factor.[71,72] Glucose tolerance factor serves to potentiate insulin activity and is, therefore, an important nutrient necessary to maintain insulin function.[71,72] Anabolic processes of protein synthesis within cells are intimately affected by chromium/insulin activity.[72] Endurance exercise has been reported to promote urinary chromium excretion.[73] Consequently, chromium supplementation during training has been proposed as a means of maintaining chromium stores and thereby maintaining insulin function.[71] The interest in chromium as a nutrient to promote muscle growth is related to the role of chromium/insulin activity in the anabolic processes of protein synthesis.[71] Although some beneficial effects of chromium supplementation (as picolinate or nicotinate) on insulin function and/or lipid profiles have been reported in patients with type 1 (insulin-dependent)[72-74] and type 2 (non-insulin-dependent)[75] diabetes mellitus and in healthy non-obese participants,[76] the effects of chromium supplementation on body composition alterations during resistance training are conflicting.

Initial studies on chromium supplementation during resistance training suggested some benefit. Evans[77] reported that chromium (as chromium picolinate) 200 μg/day supplementation during 6 weeks of resistance training promoted significantly greater gains in fat-free mass and a greater loss in fat mass compared with a placebo. Hasten and colleagues[78] reported that chromium (as chromium picolinate) 200 μ/day supplementation during 12 weeks of resistance training did not significantly affect gains in fat-free mass or 1RM strength changes in men or women. However, the women supplementing their diet with chromium experienced a significant increase in total bodyweight suggesting that women may benefit to a greater degree from chromium supplementation than men. Results from these studies served as the basis for the marketing of chromium as a nutrient to promote muscle growth and fat loss. However, results of these studies have been questioned[71] because of concerns about the methods used to determine body composition (i.e. anthropometric skin-folds).

Most studies conducted since these initial investigations have used more precise methods of assessing body composition (i.e. hydrodensiometry or DEXA) and have not supported contentions that chromium supplementation promotes lean tissue accretion during resistance training in healthy participants.[42,79-81] For example, Clancy and co-workers[79] investigated the effects of supplementing the diet with chromium (as chromium picolinate) 200 μg/day on body composition and strength alterations during 9 weeks of off-season college football resistance/agility training. These researchers reported that although chromium supplementation increased urinary chromium excretion, no significant differences were observed in hydrostatically determined body composition or strength measures. Hallmark and associates[80] and Lukaski et al.[81] also reported that 8 to 12 weeks of chromium picolinate supplementation (200 μg/day) during resistance training did not increase fat-free mass or strength. Findings from our laboratory support these contentions. We investigated the effects on body composition of supplementing the diet with a popular carbohydrate/protein weight-gain powder which contained chromium (as chromium picolinate) 800 μg/day during resistance training for 28 days.[42] DEXA body composition analysis revealed no significant difference in gains in fat-free mass between the group receiving the carbohydrate/protein/chromium supplement and a group ingesting a carbohydrate placebo.

The only recent study we are aware of that supports the contention that chromium supplementation affects body composition during training is a paper presented by Bulbulian and co-workers[82] at the 1996 American College of Sports Medicine annual meeting. These researchers investigated the effects of 24 weeks of chromium supplementation (400 μg/day as chromium picolinate) on body composition alterations in 20 male and 20 female college swimmers. Overall, results indicated that chromium supplementation increased hydrostatically determined fat-free mass (3.3%), and decreased fat mass (–4.6%) and the percentage of body fat (–6.4%) compared with the placebo group. Moreover, that the female athletes observed a greater increase in fat-free mass and loss in fat mass than the male participants. The authors noted that the greatest change in body composition parameters occurred between 12 and 24 weeks of training which suggests that the effectiveness of chromium supplementation may require longer periods of supplementation at higher doses than previously studied in conjunction with a higher volume/intensity of training.

It appears clear from these studies that short term chromium supplementation (i.e. chromium 200 to 800 μg/day, as chromium picolinate, for 4 to 12 weeks) does not promote muscle growth in healthy resistance-trained individuals. Consequently, in my view, chromium supplementation should not be recommended to athletes as a method of promoting muscle growth or fat loss. However, additional research is warranted to evaluate the effects of chromium supplementation (as picolinate and nicotinate) on insulin activity and cardiovascular risk profiles in patient populations, such as those with diabetes mellitus, who may possibly benefit from chromium supplementation. Further, given preliminary reports by Bulbulian and colleagues,[82] additional research should investigate the long term effects of supplementation with chromium 200 to 400 μg/day on body composition alterations in male and female athletes involved in intense training.

2.3 Vanadyl Sulfate

Animal studies suggest that vanadyl sulfate serves as a insulin mimetic compound.[83-86] Consequently, vanadyl sulfate has been purported to promote anabolism and muscle growth during training. Although clinical trials have indicated that vanadyl sulfate supplementation (100 mg/day for 3 weeks) in patients with type 2 diabetes mellitus[87] and sodium vanadate supplementation (125 mg/day for 2 weeks) in patients with type 1 diabetes mellitus[88] may affect insulin-sensitivity, little is known regarding the effects of vanadyl sulfate supplementation on body composition alterations during resistance training in healthy individuals.

Fawcett and co-workers[89] investigated the effects of 12 weeks of vanadyl sulfate supplementation (0.5 mg/kg/day) during 12 weeks of resistance training on body composition and strength alterations in 31 experienced male and female resistance-trained athletes. DEXA body composition measurements were determined before and after supplementation while 1RM and 10RM bench press and leg extension tests were performed at weeks 0, 4, 8, and 12 of supplementation. There were no significant differences observed between the placebo and vanadyl sulfate supplemented groups in DEXA determined fat-free mass and total body mass. In addition, limited effects were observed in 1RM and 10RM strength results. Consequently, although additional research is necessary, it does not appear that vanadyl sulfate supplementation promotes muscle growth during resistance training in healthy participants.

2.4 Boron

The mineral boron has been marketed to athletes as a dietary supplement which may promote muscle growth during resistance training. The rationale for this contention was primarily based on an initial report that boron supplementation (3 mg/day) significantly increased β-estradiol and testosterone levels in postmenopausal women consuming a diet low in boron.[90] However, subsequent studies that have investigated the effects of 7 weeks of boron supplementation (2.5 mg/day) during resistance training on testosterone levels, body composition and strength have reported no ergogenic value.[91,92] Consequently, there is no evidence at this time that boron supplementation during resistance training promotes muscle growth.

2.5 Prasterone and Androstenedione

Prasterone (dehydroepiandrosterone; DHEA) and its sulfated conjugate dehydroepiandrosterone-sulfate (DHEAS) represent the most abundant adrenal steroids in circulation.[93-95] The level of DHEAS in serum is approximately 300 to 500 times greater than that of prasterone which is approximately 20 times greater than remaining steroid hormones.[93] Prasterone and DHEAS interconvert, and therefore, DHEAS serves as a major precursor to prasterone.[94] Although prasterone is considered a weak androgen, it can be converted to the more potent androgens testosterone and dihydrotestosterone in tissues.[93,94] In addition, DHEAS can be converted into androstenedione and testosterone.[94]

Circulatory levels of prasterone have been reported to decline with age in humans.[95] The decline in prasterone levels with aging has been associated with increased deposition of intra-abdominal fat and risk to atherosclerosis.[96] Since prasterone and androstenedione are naturally occurring compounds, it has been hypothesised that dietary supplementation of prasterone and/or androstenedione may help maintain prasterone availability, maintain and/or increase testosterone levels, reduce body fat accumulation, and/or reduce risk to atherosclerosis as one ages.[95-98] In support of this contention, animal studies suggest that prasterone supplementation may decrease body fat[99-101] possibly by promoting lipolysis[101] and/or protein synthesis.[102]

However, results in human trials have been mixed. De Pergola et al.[96] reported that prasterone appeared to be the most sensitive of the androgens to body fat accumulation in premenopausal obese women. However, Denti and co-workers[95] reported that age-related declines in DHEAS levels were not related to insulin sensitivity or body composition in men while changes in DHEAS levels were negatively correlated to changes in the hip to waist ratio in women.

To date, only a few studies have investigated the effects of prasterone supplementation on body composition alterations. Nestler and co-workers[97] reported that prasterone supplementation (1600 mg/day for 28 days) in untrained healthy men significantly increased prasterone and androstenedione levels, did not significantly affect testosterone levels, promoted a 31% reduction in percent body fat, and decreased serum cholesterol levels. However, Vogiatzi and associates[103] reported that prasterone supplementation (40 mg/day for 8 weeks) in obese adolescents significantly increased testosterone levels in women but had no effect on bodyweight, percent body fat, or serum lipid levels. These findings suggest that higher dose prasterone supplementation (1600 mg/day) may provide some health benefit while low dose prasterone supplementation (40 mg/day) does not appear to affect health status. However, additional research is necessary to evaluate the effects of aging on androgen availability and whether androgen replacement therapy may affect health status.

With regards to resistance-trained athletes, prasterone and androstenedione containing dietary supplements (typically 50 to 200 mg/day of prasterone and/or androstenedione) have been marketed as a nutritional means to increase androgen availability and promote muscle growth during training. However, this author is unaware of any published studies which have investigated the effects prasterone and/or androstenedione supplementation on hormonal profiles or body composition alterations during resistance training. Until research is available to demonstrate that prasterone and/or androstenedione supplementation alters hormonal profiles and increases gains in fat-free mass during resistance training in young healthy participants, it is my view that prasterone and androstenedione supplementation should not be not recommended. In addition, since prasterone is a precursor to testosterone, some athletic governing bodies have placed this supplement on their banned substance list. Consequently, athletes involved in organised athletics, particularly at the international level, should not supplement their diet with prasterone and/or androstenedione.

3. Conclusions and Implications

Nutritional strategies for promoting lean tissue accretion during resistance training have included: overfeeding, ingesting carbohydrate/protein before exercise in order to prevent exercise-induced catabolism, ingesting carbohydrate/protein following resistance-exercise in order to promote a more anabolic hormonal profile, and nutritional supplementation with various nutrients purported to promote muscle growth. Although additional research is necessary, the following conclusions can be made from reviewing the literature in this area.

1. Overfeeding 500 to 2000 Cal/day has been reported to be an effective means of increasing body mass. However, only 30 to 40% of the mass gained has been reported to be fat-free mass. Consequently, this does not seem to be an effective strategy to promote lean tissue accretion during resistance training.

2. Ingesting a carbohydrate/protein snack (e.g. 30 to 50g carbohydrate with 5 to 10g of protein) prior to exercise may help decrease exercise-induced catabolism while ingesting a carbohydrate/protein meal or supplement (e.g. 80 to 120g of carbohydrate with 15 to 40g of protein) within 2 hours after resistance-exercise may promote a more anabolic hormonal profile and glycogen resynthesis. Whether following these strategies would affect muscle growth during resistance training remains to be determined.

3. Most studies indicate that protein (>2 g/kg/day), chromium (200 μg/day for 8 to 12 weeks), vanadyl sulfate (0.5 mg/kg/day for 12 weeks), and boron (2.5 g/day for 7 weeks) supplementation do not affect muscle growth during resistance training.

4. Additional research is warranted to evaluate the effects of glutamine, branched chain amino acid, prasterone, and androstenedione supplementation on protein synthesis, hormonal profiles and/or body composition alterations during resistance training.

5. Dietary supplementation with calcium β-HMB has been reported to promote greater gains in fat-free mass in untrained participants initiating resistance training (0.4 to 0.7kg). However, the effects of calcium β-HMB supplementation during resistance training in well-trained athletes are equivocal.

6. Dietary supplementation with creatine (20 to 25 g/day for 4 to 6 days then 2 to 25 g/day for up to 140 days) and specific nutritional formulations containing creatine (10 to 25 g/day for 28 to 84 days) have been reported to promote significant increases in fat-free mass during resistance training in well-trained athletes. Although no significant adverse effects from creatine supplementation have been reported in the scientific literature, additional long term studies are warranted to evaluate the long term safety of creatine supplementation.

7. Athletes should be educated on the importance of maintaining a well balanced, nutrient dense, energy balanced diet during resistance training as well as on the rationale, effectiveness and potential adverse effects of dietary supplements which they are contemplating adding to their diet.

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