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Effects of high-calorie supplements on body composition and muscular strength following resistance training

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Background. **Seventy-three healthy, male subjects randomly divided into 3 groups participated in a study to determine the effects of 2 high-calorie nutritional supplements on body composition, body segment circumferences, and muscular strength following a resistance-training (RT) program.**
Methods. **In addition to their normal diets group 1 (CHO/PRO; n=26) consumed a 8.4 Mj × day^{-1} (2010 kcal) high calorie, high protein supplement containing 356 g carbohydrate and 106 g protein. Group 2 (CHO; n=25) consumed a carbohydrate supplement that was isocaloric with CHO/PRO. Group 3 (CTRL; n=22) received no supplement and served as a control. All subjects were placed on a 4-day × week^{-1} RT program for 8 weeks.**
Results. **Dietary analysis revealed no significant differences in total energy consumption or nutrients at any time in the non-supplemented diets of the 3 groups. Significant ($p \leq 0.05$) increases in body mass (BM) and fat-free mass (FFM) were observed in CHO/PRO and CHO compared to CTRL. Mean (± SD) increases in BM were 3.1±3.1 kg and 3.1±2.2 kg, respectively. Fat-free mass significantly ($p \leq 0.05$) increased 2.9±3.4 kg in CHO/PRO and 3.4±2.5 kg in CHO. Muscular strength, as measured by a one-repetition maximum in the bench press, leg press, and lat-pull down increased significantly ($p \leq 0.05$) in all groups. No significant differences in strength measures were observed among groups following training.**
Conclusions. **Results indicate that high-calorie supplements are effective in increasing BM and FFM when combined with RT. However, once individual protein requirements are met, energy content of the diet has the largest effect on body composition.**

KEY WORDS: Diet - Exercise - Nutrition - Body composition.

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Many people participating in resistance-type activities such as weight lifting, weight training, and body building have used a variety of high-calorie nutritional supplements in an effort to gain body mass, muscle mass, and muscular strength. Most of the these supplements contain large amounts of energy primarily in the form of carbohydrate, protein, or some combination of the two. Although the use of these supplements is widespread, the effects of high-calorie supplements on facilitating improvements in body composition and muscular strength above and beyond that which is typically observed with resistance training alone has not been clearly delineated.

By itself, short-term resistance training lasting from 7 to 10 weeks has been shown to produce increases in muscular strength in selected exercises from 9-29% in males and females.[1] Likewise, increases in lean body mass, segmental circumferences and decreases in percentage body fat have also been demonstrated [2, 3] following resistance training. High-calorie diets, independent of resistance training, have also been shown to increase body mass and lean body mass.[4, 5] When additional energy was ingested in the form of carbohydrate, positive nitrogen balances and increases in body mass and lean body mass have also been

observed.[6] Kreider *et al.*[7] found that high-calorie carbohydrate and commercial weight-gain supplements were effective in altering body composition during resistance training. Increasing the protein content of the diet has produced mixed results. Fern *et al.*[8] observed significantly greater body mass and fat-free mass gains following 4 weeks of weight training in a group of protein-supplemented young, male subjects compared to a similarly trained group of subjects consuming an acaloric placebo.

Studies have shown that even though the protein requirement appears to be increased in individuals who resistance train, there does not appear to be any significant changes in lean body mass or muscular strength with increased protein intake.[9, 10] However, still unresolved is the question as to whether supplements containing additional energy in the form of protein and carbohydrate are more effective in improving both body composition and muscular strength than supplements which contain carbohydrate alone.

The purpose of this study was to compare the effectiveness of high-calorie nutritional supplements containing either carbohydrate or a combination of protein and carbohydrate on their abilities to alter body composition and muscular strength in a group of subjects undergoing 8 weeks of resistance training.

Materials and methods

Subjects

The subjects consisted of 73 healthy males between the ages of 18-35 years (mean age±SD = 23.1±4.4 yrs). All potential subjects were initially screened with regard to their health history, weight training experience and participation in other physical activities. Only individuals who were beginning weight trainers and mildly physically active were selected to participate in the study. Following an orientation session explaining the testing and training procedures, subjects completed informed consents in accordance with institutional guidelines established for the protection of human subjects.

Subjects were randomly assigned to 1 of 3 groups. Group 1 (CHO/PRO; n=26; age=23.0±4.6 yrs; height=176.6±8.4 cm; body mass=76.7±13.6 kg) consisted of subjects administered a commercially-available, high-calorie carbohydrate and protein supplement. Group 2 (CHO; n=25; age=23.4±4.7 yrs; height=179.9±9.4 cm; body mass=76.1±13.0 kg) consisted of subjects administered a carbohydrate supplement that was isocaloric with the carbohydrate and protein supplement. Group 3 (CTRL; n=21; age=23.1±3.9 yrs; height=171.7±8.0 cm; body mass=77.7±14.7 kg) served as the control group and consisted of subjects who were administered no supplements. All subjects were requested to minimize participation in aerobic activities and maintain their normal diets during the course of the study. The primary investigators and training supervisors were unaware of the group assignments.

Testing procedures

Height and body mass measurements were made using a calibrated Detecto medical scale. Measurements were made while the subjects were wearing only swim suits. To determine body segment circumferences, duplicate measurements were made in rotational order at each of 7 sites using a fiberglass reinforced measuring tape using the protocols established by Lohmann.[11]

Hydrostatic weighing was used to determine body density, percentage of body fat, fat mass, and fat-free mass. Percent body fat was calculated using the equation developed by Siri.[12] Residual lung volumes were determined by a closed-circuit helium dilution method. A Collins RS 10 l water-sealed spirometer (Warren E, Collins, Inc. Braintree, MA, USA) with a thermal conductivity, temperature compensated helium analyzer was used to make the measurements. The spirometer bell was filled with 2 l of room air, 600 ml of helium, and 100 ml of oxygen. The gain of the helium analyzer was then set, and an additional 2.3 l of room air was added to the spirometer bell. Subjects were then connected to the spirometer mouthpiece and with the nose clip secured on their nose, began normal tidal breathing. Subjects were switched into the closed-circuit system and continued to breath normally for approximately 5-7 min to allow the helium in the bell to reach equilibrium with the lungs. Tidal breathing was maintained by the addition of oxygen into the spirometer every 30 sec during the test. Expired carbon dioxide was absorbed with the use of a trap consisting of barium hydroxide lime. Once equilibrium was established, the subjects were asked to perform a vital capacity test so that expir-

atory reserve volume could be measured. Following the vital capacity test, subjects were disconnected from the spirometer and given adequate time to allow the helium to wash out of the lungs. A minimum of 2 tests was performed on each subject. Tests were repeated until measurements agreed to within 10%.

The three criterion strength measures were the free weight bench press, Cybex lat pull down and horizontal leg press machines. All subjects were asked to perform a one repetition maximum (1RM) test using the previously described procedures.[13]

All pretest measurements were completed 1 week prior to the first week of training. Post-test measurements were completed within 1 week following training. For each procedure, the subjects were tested by the same individual during the pretest and post-test conditions.

Diet supplementation

Subjects in the 2 supplemented groups received coded boxes containing either a commercially-available carbohydrate-protein supplement (CHO/PRO) or an isocaloric carbohydrate supplement (CHO). So that the subjects in CHO/PRO and CHO were unaware of the type of supplement being used, supplements were made to look similar and were packaged in identical coded boxes. In order to maintain the palatability of the supplements, subjects were instructed to mix their contents with 2% non-fat milk. This added a small amount of protein and fat to the each type of supplement. Three cups of the CHO/PRO supplement mixed with 3.0 cups milk contained 69.6% (356 g) carbohydrate, 20.7% (106 g) protein, 9.7% (18 g) fat, and approximately 8.41 Mj (2010 kcal). On the basis of body mass, the additional amount of protein consumed per day (mean±SD) was 1.6 ± 0.3 g $\times$ kg^{-1} day^{-1}. The contents of 3.0 cups of the isocaloric CHO supplement mixed with 3.0 cups milk contained 89.1% (450 g) carbohydrate, 4.7% (24 g) protein, 6.2% fat (14 g), and approximately (8.46 Mj) 2020 kcal. The amount of protein contained in this supplement based upon body mass was 0.3 ± 0.1 g $\times$ kg^{-1} day^{-1}. Subjects were instructed to ingest one-half of the supplement preferably between the morning and afternoon meal and the other half before bedtime. Packets of the supplements were distributed to the subjects every 2 weeks. The code was not revealed to the primary investigators until the conclusion of the study.

To determine changes in diet and caloric intake, all subjects kept 3 day diet histories. These were completed during the first, fourth and eighth week of training. Data were analyzed using Nutritionist III, Version 7 computer software (N^2 Computing, Salem, Oregon). The analyzed diets did not include the addition of either the CHO/PRO or isocaloric CHO supplement.

Training protocol

All subjects trained 4 days per week for 8 weeks. The training routine was identical for all 3 groups and included training on Monday and Tuesday, followed by a rest day on Wednesday, and training again on Thursday and Friday. Saturday and Sunday were considered rest days. Each training session lasted between 60 and 90 min.

At the fitness facility, subjects were required to perform a general, non-specific warm-up consisting of 5 to 10 min on either a stationary bike, treadmill, stepper, or rowing machine before engaging in the weight training program. All subjects performed the following movements on Mondays and Thursdays: squat, leg curls, lat pulldowns, EZ curl, and abdominal crunches. On Tuesdays and Fridays the incline press, upright row, bench press, triceps pushdown, and abdominal crunch were performed. A specific warm-up consisting of 2 warm-up sets performed at 45 and 60% 1RM were completed for the squat, pulldown, EZ curl, incline press and bench press movements as indicated by the training protocol. The actual training volume and intensity were defined as 4 sets of 8 repetitions using approximately 70% of a 1RM for all exercises. So that the requirement of four workouts per week was adhered to, all missed training sessions were made up by the subjects on either Wednesday or Saturday. All subjects completed 32 training sessions.

Prior to the start of the training program, all subjects were tested for a 1RM in each of the training lifts. On the first and second day of the second week and each subsequent week, the training load for each exercise was increased, but only if the number of sets and repetitions could be maintained. Increases in training loads for the upper body movements were 2.2 to 4.4 kg, while loads for lower body movements were increased 2.2 to 9.0 kg. To insure that the appropriate training intensity was maintained throughout the study, the IRM for all exercises was retested at

TABLE I.—*Energy and nutrient intake without supplementation during weeks 1, 4, and 8 (mean±SD).*

Groups	Weeks	Mjoules (× day^{-1})	kcal (× day^{-1})	CHO (%)	CHO (g)	Protein (%)	Protein (g)	Protein (g × kg^{-1} × day^{-1})	Fat (%)	Fat (g)
CHO/PRO	1	9.3±3.7	2220.7±876.6	46.4±8.9	254.6±92.2	19.1±4.7	107.6±51.8	1.4±0.7	32.6±7.4	79.5±32.4
	4	9 9±3.3	2366.4±784.0	48.2±8.1	289.9±108.3	19.8±7.3	114.9±51.2	1.5±0.7	31.1±5.2	83.9±32.7
	8	10.1±4.4	2427.1±1049.8	44.4±11.6	264.1±100.5	20.3±6.1	142.2±89.6	1.8±1.0	31.9±8.4	90.4±51.1
CHO	1	10.0±3.2	2394.1±764.4	51.1±9.6	311.4±120.3	18.0±3.6	110.2±43.1	1.4±0.6	29.6±8.1	78.4±31.2
	4	10.6±3.9	2524.0±941.7	52.2±7.7	331.8±126.4	17.7±3.1	111.4±41.6	1.5±0.7	29.2±6.9	97.6±63.4
	8	9.7±3.2	2327.9±773.7	49.8±9.3	281.5±78.6	18.2±4.9	106.0±45.7	1.3±0.6	31.8±9.3	83.5±42.4
CTRL	1	12.2±4.4	2929.1±1042.0	49.9±7.4	368.6±137.4	15.8±3.3	119.4±61.4	1.5±0.8	29.0±6.8	96.0±42.0
	4	10.0±3.7	2402.1±878.0	51.5±9.6	323.3±133.1	16.8±5.3	100.7±53.5	1.3±0.7	27.6±5.7	74.5±31.3
	8	10.3±4.3	2461.0±1023.0	52.0±7.3	320.1±136.9	16.3±4.7	99.9±45.8	1.3±0.6	29.3±5.7	81.2±35.5

the beginning of week 5 and the training loads were readjusted as needed. Each subject was issued a training notebook in which all sets, repetitions, and weights were recorded. The notebooks were reviewed daily by the training supervisor to insure exercise compliance and to address any questions the subjects might have posed.

Statistical analysis

Paired "t"-tests were used to determine differences between means within each group from pretest to post-test conditions. Absolute differences in the pre- and post-test measurements among groups were analyzed using a one-way analysis of variance with a Student-Newman-Keul *posthoc* analysis. The Statistical Package for Social Sciences (SPSS) was used for data analysis. Statistical significance was established at the $p \leq 0.05$ level of probability.

Results

Prior to taking into account the supplements, all three groups had energy intakes that were within the normal range for age and gender.[14] This was true for the proportion of energy in the diet derived from protein, carbohydrate, and fat. No significant differences were observed were found within or between the 3 groups with regard to the energy intake per day or the percentage of energy in the diet derived from protein, carbohydrate, and fat during the first, fourth or eighth week (Table I).

Addition of the supplements resulted in significantly higher energy intakes for CHO/PRO and CHO as compared to CTRL. Averaged across the 3 time periods, energy intakes for CHO/PRO and CHO were 18.2±3.8 Mj × day^{-1} (4348.0±902.0 kcal × day^{-1}) and 18.2±3.35 Mj × day^{-1} (4339±800.0 kcal × day^{-1}). By contrast, CTRL had an average energy intake of 10.9±4.1 Mj × day^{-1} (2597.3±981.0 kcal × day^{-1}). The carbohydrate supplement taken by CHO resulted in significantly higher average total carbohydrate intakes (758±81.6 g × day^{-1}) than either CHOIPRO (625.5±84.6 g × day^{-1}) or CTRL (337.3±125.4 g × day^{-1}). As a result of consuming the carbohydrate/protein supplement, CHO/PRO had significantly higher total average protein intakes (3.0±0.9 g × kg^{-1} × day^{-1}) than either CHO (1.7±0.6 g × kg^{-1} × day^{-1}) or CTRL (1.4±0.7 g × kg^{-1} × day^{-1}).

Pretest and post-test values for all measurements are given in Table II. No statistically significant differences in body mass were observed among the 3 groups under the pretest conditions for any of the measurements. Significant increases in body mass were observed in CHO/PRO and CHO from pretest to post-test conditions. The average gain in body mass for CHO/PRO was 3.1±3.1 kg and for CHO it was 3.1±2.2 kg. No statistically significant increase in body mass was found in CTRL from pretest to post-test. When the absolute difference between the pretest and post-test conditions was taken into account, both CHO/PRO and CHO had significantly greater increases in body masses than C (Fig. 1).

Under the pretest conditions, no signidicant differences were observed among the 3 groups. All 3 groups made significant gains in fat-free mass from the pretest to post-test. CHO/PRO gained an average of 2.9±3.4 kg, while CHO and CTRL gained 3.4±2.5 kg and 1.4±1.7 kg, respectively. CHO/PRO and CHO gained significantly more fat-free mass than CTRL. However CHO/PRO and CHO were not significantly different from one another.

TABLE II.—*Pre- and post-training values for body composition, anthropometric and muscular strength measurements.*

Measurements	Group 1-CHO/PRO		Group 2-CHO		Group 3-CTRL	
	Pre (mean±SD)	Post (mean±SD)	Pre (mean±SD)	Post (mean±SD)	Pre (mean±SD)	Post (mean±SD)
Body composition						
Body mass (kg)	76.7±13.6	79.8*±13.4	76.1±13.0	79.2*±13.5	77.7±14.6	78.30±3.1
Body fat (%)	15.1±6.0	14.9±5.6	12.4±6.0	11.4±5.7	13.4±7.0	12.1*±7.0
Fat mass (kg)	12.0±6.0	12.2±5.3	9.7±5.3	9.4±5.9	11.1±8.3	10.3*±8.3
Fat-free mass (kg)	64.8±10.2	67.6*±10.8	66.4±10.8	69.8*±10.7	66.6±9.0	68.0*±8.4
Circumferences						
Right upper arm (cm)	30.6±3.2	31.9*±2.9	30.3±3.2	31.4*±2.9	31.5±3.8	32.0*±3.9
Right forearm (cm)	27.8±1.8	28.35*±1.7	27.6±2.2	28.2*±2.1	28.4±2.1	28.5±2.3
Chest (cm)	97.1±7.6	100.2*±6.9	96.2±7.8	99.1*±7.8	98.5±8.4	99.7*±7.9
Abdomen (cm)	82.6±8.3	83.7±8.0	80.7±7.8	81.4±7.4	83.2±9.7	83.0±9.3
Buttocks (cm)	98.5±7.2	98.9±7.9	97.7±6.9	99.1*±6.6	98.4±8.2	97.7±7.9
Thigh (cm)	59.1±6.0	60.4*±6.5	57.7±5.7	60.0*±5.5	59.4±5.4	60.1±5.4
Calf (cm)	38.2±3.2	38.1±3.2	37.5±3.4	37.6±3.3	37.8±2.8	37.6±2.9
Strength (1RM)						
Leg press (kg)	189.5±46.5	235.9*±64.1	185.8±53.0	211.1*±49.6	206.3±40.7	235*±50.1
Bench press (kg)	73.5±21.4	87.8*±22.1	72.8±19.7	83.1*±21.6	87.9±24.7	98*±24.1
Lat pull down (kg)	32.6±6.5	39.4*±6.0	34.0±7.2	40.0*±7.5	36.2±5.8	41.1*±6.4
Total lifted (kg)	295.6±67.5	363.1*±84.1	292.6±75.4	334.2*±72.3	330.4±63.7	374.1*±71.8

*) Significantly different from pretraining ($p \leq 0.05$).

No statistically significant differences in the relative percentage of body fat or fat mass were observed among the 3 groups under the pretest conditions. Only CTRL was observed to have a decrease in fat mass and percent body fat from pretest to post-test conditions. These decreases were not significantly different than the other 2 groups.

Right upper arm circumferences significantly increased from pretest to post-test conditions in all 3 experimental groups. The mean (±SD) increases for CHO/PRO, CHO, and CTRL were 1.3±1.0 cm, 1.1±0.8 cm, and 0.5±0.9 cm, respectively. Both CHO/PRO and CHO made significantly greater gains in circumference than CTRL. All 3 groups significantly increased in chest circumference from test to post-test conditions. Mean (±SD) absolute increases for CHO/PRO, CHO, and CTRL were 3.1±2.8 cm, 2.9±2.1 cm, and 1.2±2.3 cm, respectively. Increases in chest circumference were significantly greater in the CHO/PRO and CHO groups compared to CTRL. Significant increases in right forearm and thigh circumferences were observed only in CHO/PRO and CHO from the pretest to post-test. Right forearm circumferences were significantly greater in CHO/PRO and CHO compared to CTRL. Buttocks circumferences were found to have significantly increased only in the CHO group. No other differences in circumferences were observed.

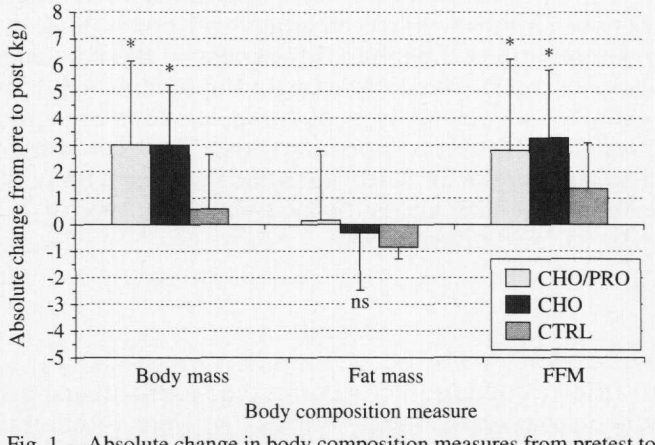

Fig. 1.—Absolute change in body composition measures from pretest to post-test conditions. * = significantly different from control (CTRL) group ($p \leq 0.05$). NS = no significant difference among groups ($p \geq 0.05$).

All groups significantly increased muscular strength, both in individual lifts and total mass lifted as a consequence of the training program. However, there were no significant differences in strength gained in any of the measurements among the 3 groups (Fig. 2).

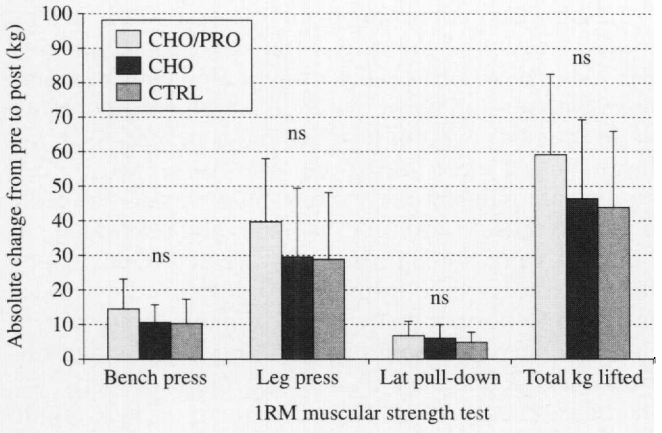

Fig. 2.—Absolute change in muscular strength measures from pretest to post-test conditions. NS = no significant difference among groups ($p \geq 0.05$).

Discussion and conclusions

Results from this study indicate that the combination of a high volume, moderate intensity resistance training program and additional energy intake from supplementation resulted in increased body mass and fat-free mass. The increased body mass and fat-free mass observed in both of the supplemented groups was significantly greater than that found in a similarly trained group of subjects who did not use supplements. These results are in agreement with Rinehardt[15] who found significant increases in body mass and fat-free mass in subjects who were ingesting supplements of 2.1 Mj $\times$ day^{-1} (500 kcal $\times$ day^{-1}) containing either 40% or 65% carbohydrate. The results are also in agreement with Krieder *et al.*[7] who found that the intake of a pure high-calorie carbohydrate supplement was as effective in promoting lean body mass during resistance training as either a high-calorie CHO/PRO supplement or one containing high-calories primarily in the form of CHO plus compounds such as creatine monohydrate, taurine, and l-glutamine. A primary difference between the current investigation and that of Kreider *et al.*[7] was that the supplements were not isocaloric in the latter study. The increased energy expenditure of a resistance training program of the type used in the current study may have been sufficient to offset the increased caloric intakes of CHO/PRO and CHO resulting in little change in the percentage of body fat over the course of the 8 week training period.

Supplemental protein in the diet did not result in any additional gain in either body mass, fat-free mass, or muscular strength compared to an isocaloric carbohydrate supplement. While the carbohydrate/protein supplement provided an additional 106 g of protein per day, it did not appear to be any more effective than the isocaloric carbohydrate supplement in producing changes in body mass or fat-free mass, since subjects in the carbohydrate supplement group were apparently receiving adequate amounts of protein m their regular non-supplemented diets. It has been suggested that the timing of supplement intake may be a factor in promoting protein synthesis and lean mass development.[16] Although the timing of supplement intake was not controlled for in the current study, previous studies[17-19] have shown that CHO and CHO/PRO supplements taken soon after resistance exercise resulted in increased plasma insulin and growth hormone and stimulation of muscle protein synthesis. In addition, Forbes *et al.*[20] found that subjects who were overfed for a period[21] days had elevations in plasma concentrations of somatomedin C, IGF-1, testosterone and insulin. It was suggested that the anabolic properties of these hormones may have contributed to an observed increase in lean tissue. It is possible that in the current study, an increase in anabolic hormone levels in combination with the increased energy intake may have produced an overall environment conducive to the development of lean body mass in most of the participants. Since hormone concentrations were not measured in this study, the relationship between anabolic hormone levels and energy intake can only be speculated.

A number of studies have shown that individuals who are training heavily may require increased amounts of protein ranging from 1.2 to 1.8 gm protein $\times$ kg^{-1} $\times$ day^{-1}.[10, 21, 22] It has been suggested that high protein intakes combined with heavy resistance training could result in greater gains in muscle mass and muscular strength than with lower protein intakes primarily because of a greater positive nitrogen balance.[23] In the present study, subjects in all 3 groups, on average, obtained considerably more protein from their normal, non-supplemented diets than the recommended dietary allowances and were within the recommended range for individuals who regularly train. With only their normal dietary intake of protein, the control group (CTRL) made relatively small gains in body mass and fat-free mass compared to the supplemented groups. However, the group with the highest average daily protein intake did not make significantly greater gains in

body mass or fat-free mass than the isocaloric carbohydrate group. It is possible that there may be an upper limit of dietary protein's effect on protein synthesis. Tarnopolsky *et al.*[10] found that when dietary protein intake was increased from 0.86 to 1.4 $g \times kg^{-1} \times day^{-1}$ whole body protein synthesis was increased in men who resistance trained. When intakes were increased to 2.4 $g \times kg^{-1} \times day^{-1}$ there was no further increase in protein synthesis. Furthermore, Campbell *et al.*[24] have shown that nitrogen retention is greater in individuals with lower protein intakes. The results from the present study are in agreement with previous studies and support the concept that once individual protein requirements are met, the total energy intake may be the most important dietary factor related to body composition changes rather than the specific ingredients used to provide additional energy.[25, 26]

Improvements in muscular strength are generally expected when individuals undergo a well-designed weight training program. In the present study, the 3 measures selected to evaluate changes in muscular strength were the horizontal leg press, lat pull down, and free weight bench press. All 3 groups made statistically significant increases in the 3 criterion strength measures from pretest to post-test. CHO/PRO had the largest pretest to post-test absolute increases in all 3 strength tests. However, when the 1RM strength scores of all 3 groups were compared to each other at the post-test, no significant differences were observed. Although the supplemented groups gained significantly in overall body mass and fat-free mass compared to the non-supplemented group, there were no statistically significant differences in muscular strength among the groups.

Muscular strength gains are a consequence of central nervous system (CNS) adaptations, muscular hypertrophy, or some combination of the two.[27 28] Increases in fat-free mass as a result of muscle hypertrophy can have a direct effect on muscular strength. Although fat-free mass increased in the present study, is not possible from this study to ascertain the individual contributions of the CNS or muscular hypertrophy to the expression of muscular strength. Due to the relatively short-term duration of the training study it is possible that much of the increase in strength in all groups was due to neural adaptations. A longer duration study may have resulted in the supplemented groups expressing larger gains in strength because of an increased muscle mass.

In summary, the results from this study indicate that males, who increased caloric intake by approximately 8.37 $Mj \times day^{-1}$ (2000 $kcal \times day^{-1}$) above their normal daily intakes and participated in a high volume, moderate intensity weight training program emphasizing large muscle mass multi-joint exercises, experienced significant gains in body mass, fat-free mass, muscle size, and muscle strength. Fat mass and percentage of body fat were not significantly affected. Conversely, the same resistance training program used by males following a normal diet without supplementation, produced relatively smaller gains in body mass and fat-free mass, a decrease in the percentage of body fat, increased muscle mass and increased muscle strength. The results suggest that total energy intake was the most important dietary component affecting changes in body composition. Although all 3 groups significantly increased muscular strength, there was no significant difference among the groups. This would indicate that gains in muscular strength were a result of training, with supplementation having no statistically significant effect.

References

1. Kraemer WJ, Deschenes M, Fleck S. Physiological adaptations to resistance exercise: implications for athletic conditioning. Sports Med 1988;6:246-56.
2. Katch FI, Drumm SS. Effects of different modes of strength training on body composition and anthropometry. Clin Sports Med 1986;5(3):413-59.
3. Stone MH, Fleck, SJ, Triplett NT, Kraemer WJ. Health- and performance-related potential of resistance training. Sports Med 1991;11(4):210-31.
4. Miller DS, Mumford P. An experimental study of overeating low- or high-protein diets. Am J Clin Nutr 1967;20:1212-29.
5. Forbes OB, Brown MR, Welle SL, Lipinski BL. Deliberate overfeeding in women and men: energy cost and composition of the weight gain. Br J Nutr 1986;56:1-9.
6. Welle S, Matthews DE, Campbell RG, Nair S. Stimulation of protein turnover by carbohydrate overfeeding in men. Am J Physiol 1989;57(Endocrinol Metab 20):E413-7.
7. Kreider RB, Klesges R, Harmon K, Grindstaff P, Ramsey L, Bullen D *et al.* Effects of ingesting supplements designed to promote lean tissue accretion on body composition during resistance training. Int J Sports Nutr 1996;6:234-46.
8. Fern EB, Bielinski RN, Schutz Y. Effects of exaggerated amino acid and protein supply in man. Experientia 1991;47:168-72.
9. Lemon PWR, Tarnopolsky MA, MacDougall JD, Atkinson SA. Protein requirements and muscle mass/strength changes during intensive training in novice bodybuilders. J Appl Physiol 1992;73(2): 767-75.
10. Tarnopolsky MA, Atkinson SA, MacDougall JD, Chesley A, Phillips S, Schwarcz HP. Evaluation of protein requirements for strength trained athletes. J Appl Physiol 1992;73(5):1986-95.
11. Lohmann TO. Anthropometry and body composition. In: Lobmann TG, Martorell R, editors. Anthropometric standardization reference manual. Campaign, IL: Human Kinetics Publishers, 1988.

12. Siri WE. Body composition from fluid spaces and density: analysis of methods. In: Brozek J, Hensehel A, editors. Techniques for measuring composition. Washington DC: National Academy of Sciences, National Research Council, 1961:223-4.
13. Kraemer WJ, Fry AC. Strength testing: development and evaluation of methodology. In: Maud PJ, Foster C, editors. Physiological assessment of human fitness. Champaign IL: Human Kinetics Publishers, 1995:121.
14. National Research Council. Recommended dietary allowances. 10th edition. Washington, DC: National Academy Press, 1989.
15. Rinehardt KF. Effect of diet on muscle and strength gains during resistive training. In: Garrett WE, Malone TR, editors. Report of the Ross Symposium on muscle development: nutritional alternatives to anabolic steroids. Columbus OH: Ross Laboratories, 1988: 78-83.
16. Houston ME. Gaining weight: the scientific basis of increasing skeletal muscle mass. Can J Appl Physiol 1999;24(4):305-16.
17. 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(Endocrinol Metab 36):E122-9.
18. Chandler RM, Byrne HK, Patterson JG, Ivy JL. Dietary supplements affect the anabolic hormones after weight-training exercise. J Appl Physiol 1994;76:839-45.
19. Roy BD, Tarnopolsky MA, MacDougall JD, Fowles J, Yaresheski KE. Effect of glucose supplement timing on protein metabolism after resistance training. J Appl Physiol 1997;82:1882-8.
20. Forbes GB, Brown MR, Welle SL, Underwood LE. Hormonal response to overfeeding. Am J Clin Nutr 1989;49:608-11.
21. Lemon PWR. Is increased dietary protein necessary or beneficial for individuals with a physically active lifestyle? Nutr Rev 1996;54(4): S169-75.
22. Walberg Rankin J. Role of protein in exercise. Clin Sports Med 1999;18(3):499-511.
23. Lemon PWR, Proctor DN. Protein intake and athletic performance. Sports Med 1991;12(5)313-25.
24. Campbell WW, Crim MC, Young VR, Joseph LJ, Evans WJ. Effects of resistance training and dietary protein intake on protein metabolism in older adults. Am J Physiol 1995;268(Endocrinol Metab 31):E1143-53.
25. Kleiner SM. Performance-enhancing aids in sport: health consequences and nutritional alternatives. J Am Coll Nutr 1991;10(2):163-76.
26. Forbes GB. Lean body mass-body fat interrelationships in humans. Nutr Rev 1987;45(8):225-31.
27. Hakkinen K. Neuromuscular and hormonal adaptations during strength and power training. J Sports Med 1989;29(1):9-26.
28. Kraemer WJ, Fleck SJ, Evans WJ. Strength and power training: physiological mechanisms of adaptation. Exerc Sport Sci Rev 1996;24:363-97.