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Effect of Protein-Supplement Timing on Strength, Power, and Body-Composition Changes in Resistance-Trained Men

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The effect of 10 wk of protein-supplement timing on strength, power, and body composition was examined in 33 resistance-trained men. Participants were randomly assigned to a protein supplement either provided in the morning and evening ($n = 13$) or provided immediately before and immediately after workouts ($n = 13$). In addition, 7 participants agreed to serve as a control group and did not use any protein or other nutritional supplement. During each testing session participants were assessed for strength (one-repetition-maximum [1RM] bench press and squat), power (5 repetitions performed at 80% of 1RM in both the bench press and the squat), and body composition. A significant main effect for all 3 groups in strength improvement was seen in 1RM bench press (120.6 ± 20.5 kg vs. 125.4 ± 16.7 at Week 0 and Week 10 testing, respectively) and 1RM squat (154.5 ± 28.4 kg vs. 169.0 ± 25.5 at Week 0 and Week 10 testing, respectively). However, no significant between-groups interactions were seen in 1RM squat or 1RM bench press. Significant main effects were also seen in both upper and lower body peak and mean power, but no significant differences were seen between groups. No changes in body mass or percent body fat were seen in any of the groups. Results indicate that the time of protein-supplement ingestion in resistance-trained athletes during a 10-wk training program does not provide any added benefit to strength, power, or body-composition changes.

Keywords: sport nutrition, ergogenic aid, athletes, weight training

It is well accepted that strength and power athletes have a protein requirement that might be at least twice that of sedentary individuals and perhaps 30–50% greater than that of endurance athletes (Lemon, Tarnopolsky, MacDougal, & Atkinson, 1992; Tarnopolsky et al., 1992). The greater amount of protein needed by these athletes is thought to enhance the recovery and remodeling processes of muscle fibers that have been damaged or disrupted during resistance exercise

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(Tipton et al., 2004). Recent investigations have reported a reduction in muscle damage, attenuation of force decrements, and enhanced recovery from resistance exercise in individuals using protein and/or amino acid supplements (Kraemer et al., 2006; Ratamess et al., 2003). A recent area of focus in studies examining protein supplementation has become protein consumption's timing in regard to the workout.

Studies examining the acute effect of protein ingestion have demonstrated that ingestion occurring close to the workout (e.g., immediately before or within an hour postexercise) significantly enhances muscle protein-synthesis rate and muscle protein accretion when compared with when ingestion is delayed for longer periods of time (Rasmussen, Tipton, Miller, Wolf, & Wolfe, 2000; Tipton, Ferrando, Phillips, Doyle, & Wolfe, 1999; Tipton et al., 2001). These results suggest that protein-supplement timing might be critically important in stimulating muscle adaptations that occur during prolonged training. However, there are only a limited number of studies that have examined the effect of protein timing in prolonged training studies.

The effect of protein-ingestion timing in training studies is not clear. Several investigations have shown that protein ingestion before and immediately after resistance exercise is a potent stimulus for muscle size and performance gains compared with carbohydrate-only supplements in young (~19–23 years old) previously trained (Hoffman, Ratamess, Kang, Falvo, & Faigenbaum, 2007) or untrained individuals (Andersen et al., 2005; Willoughby, Stout, & Wilborn, 2007), whereas no change was seen in muscle mass or strength after 12 weeks of supplementation in untrained elderly men (Candow, Chilibeck, Facci, Abeysekara, & Zello, 2006). The differences between these studies are not clear but might be attributable to differences in the endocrine response to resistance exercise between young and older men (Kraemer et al., 1999). Only a limited number of studies have actually compared various protein-timing strategies. Esmarck et al. (2001) examined the effect of protein timing in untrained elderly participants (74.1 ± 1 year) during a 12-week resistance-training program. Participants consumed a protein supplement (10 g protein, 7 g carbohydrate, and 3 g fat) immediately or 2 hr after each resistance-exercise session (three times per week). Results showed that muscle cross-sectional area and individual muscle-fiber area increased significantly in the participants who consumed the supplement immediately postexercise, but muscle-fiber area did not change in those who consumed the supplement 2 hr after each training session. In a study on young (21–24 years) recreationally trained male bodybuilders, consumption of a supplement containing protein (40 g of whey isolate) and carbohydrate (43 g of glucose) immediately before and after resistance-exercise sessions resulted in significantly greater gains in lean body mass, increases in cross-sectional area of Type II fibers, and increases in contractile protein content compared with participants consuming the protein–carbohydrate supplement in the morning and evening (Cribb & Hayes, 2006).

The examination of protein timing has generally used untrained or recreationally trained participants. The understanding of how protein timing affects resistance-trained athletes is limited. Thus, the purpose of this study was to examine the role of protein timing on resistance-trained athletes participating in a 10-week off-season conditioning program.

Materials and Methods

Participants

Thirty-three male strength and power athletes volunteered for this study. After an explanation of all procedures, risks, and benefits each participant gave his informed consent to participate in this study. The Institutional Review Board of the College of New Jersey approved the research protocol. Participants were not permitted to use any additional nutritional supplementation and had not consumed anabolic steroids or any other anabolic agents known to increase performance for the previous year. Screening for anabolic-steroid use and additional supplementation was accomplished via a health questionnaire filled out during participant recruitment.

Participants were randomly assigned to either a protein supplement provided in the morning and evening (a.m./p.m.; $n = 13$; 19.6 ± 1.3 years, 183.4 ± 5.1 cm, 102.3 ± 18.9 kg) or provided immediately before and immediately after workouts (pre–post; $n = 13$; 19.9 ± 1.3 years, 183.4 ± 5.1 cm, 95.1 ± 14.4 kg). To compare the effect of supplementation with no supplementation, 7 participants agreed to serve as a control group ($n = 7$; 20.7 ± 1.1 years, 179.4 ± 9.4 cm, 100.1 ± 27.2 kg) and did not use any protein or other nutritional supplement. Most of the participants (30/33) were athletes from the college's football team with at least 2 years (5.9 ± 1.8 years) of resistance-training experience. The remaining participants competed in power lifting and were randomly assigned to one of the three groups. All groups performed the same resistance-training program for 10 weeks. The training program was a 4-days-per-week split routine (see Table 1) that was supervised by laboratory personnel. All participants completed a daily training log, which was collected by research investigators on a weekly basis.

Testing Protocol

Participants reported to the human performance laboratory (HPL) on two separate occasions. The first testing session occurred before the onset of protein supplementation (Week 0), and the second testing session occurred at the conclusion of the 10-week supplementation program (Week 10). All testing sessions occurred at the same time of day.

Body Composition

Body composition was determined using whole-body dual-energy X-ray absorptiometry (Prodigy, Lunar Corp., Madison, WI). Total-body estimates of percent fat, bone-mineral density, and bodily content of bone, fat, and nonbone lean tissue were determined using the manufacturer's recommended procedures and supplied algorithms. All measures were performed by the same technician, and the intraclass correlation coefficient for bone-mineral density was $R = .99$. Quality assurance was achieved by daily calibrations performed before all scans using a calibration block provided by the manufacturer.

Table 1 10-Week Resistance-Training Program

Exercise	Weeks 1–5 (Sets × Reps)	Weeks 5–10 (Sets × Reps)
Days 1 and 3		
high pull	—	4 × 4–6
bench press	4 × 8–10	4 × 6–8
incline bench press	3 × 8–10	3 × 6–8
incline flies	3 × 8–10	3 × 6–8
seated shoulder press	4 × 8–10	—
dumbbell shoulder press/behind-the-neck shoulder press	—	4 × 6–8
lateral raises/dumbbell front raise	3 × 8–10	3 × 6–8
triceps push-downs	3 × 8–10	3 × 6–8
triceps push-downs/dumbbell extensions	3 × 8–10	3 × 6–8
partner neck exercise	2 × 10	3 × 10
Days 2 and 4		
squat	4 × 8–10	4 × 6–8
dead lift/Romanian dead lift	4 × 8–10	3 × 6–8
dumbbell lunge/dumbbell step-ups	3 × 8–10	3 × 6–8
leg curls	3 × 8–10	—
standing calf raises	4 × 8–10	3 × 6–8
pull-ups	3 × max	
lat pull-down	4 × 8–10	4 × 6–8
seated row	4 × 8–10	4 × 6–8
dumbbell biceps curls	4 × 8–10	4 × 6–8
trunk and abdominal routine	3 × 10	3 × 10

Note. All exercises performed to a repetition-maximum range. Lines with two exercises required the athlete to perform the first exercise during the first training session and the second exercise during the second training session.

Strength Measures

During each testing session, participants performed a 1-repetition-maximum (1RM) strength test for the squat and bench-press exercises. The 1RM tests were conducted as described by Hoffman (2006). Each participant performed a warm-up set using a resistance that was approximately 40–60% of his perceived maximum and then performed three or four subsequent attempts to determine the 1RM. A 3- to 5-min rest period was provided between lifts. No bouncing was permitted for the bench-press exercise, because this would have artificially boosted strength results. Bench-press testing was performed in the standard supine position. The participant lowered an Olympic weightlifting bar to midchest level and then pressed the weight until his elbows were fully extended. The squat exercise required the participant to rest an Olympic weightlifting bar across the trapezius at a self-chosen location. The squat was performed to the parallel position (closely monitored by research staff), which was achieved when the greater trochanter of the femur was lowered to the same level as the knee. The participant then lifted the weight until his knees were extended.

Power Measurements

Upper and lower body power during the bench-press and squat exercise was measured with a Tendo power-output unit (Tendo Sports Machines, Trencin, Slovak Republic). The Tendo unit consists of a transducer attached to the end of the barbell that measures linear displacement and time. Subsequently, bar velocity was calculated and power was determined when bar load was manually input. Both peak and mean power output were recorded for each repetition and set and used for subsequent analysis. Power analyses were performed with each participant performing five repetitions at 80% of their 1RM in both exercises. Order of exercise testing was randomly determined. Test–retest reliabilities for these power measurements have been established in our laboratory to be $R > .92$.

Dietary Recall

Three-day dietary records were completed during the week before the onset of the study and during Week 9 of the study. Participants were instructed to record as accurately as possible everything they consumed during the day including the supplement and between-meal and late-evening snacks. FoodWorks dietary-analysis software (McGraw Hill, New York, NY) was used to analyze dietary recalls.

Supplement Schedule

The protein supplement was in liquid form and consisted of 42 g of a proprietary blend of protein (enzymatically hydrolyzed collagen protein isolate, whey protein isolate, and casein protein isolate), 2 g of carbohydrate, and 0 g of fat. Laboratory analysis of the supplement reported by the company (IDS Sports, Oviedo, FL) showed that it contained 3.6 g of leucine, 3.0 g of isoleucine, 1.4 g of valine, 5.0 g of alanine, 3.0 g of arginine, 2.3 g of aspartic acid, 4.0 g of glutamic acid, 9.1 g of glycine, 2.3 g of lysine, 2.0 g of phenylalanine, 5.8 g of proline, 1.2 g of serine, 1.0 g of tyrosine, 0.9 g of threonine, 0.9 g of methionine, 0.4 g of cystine, 0.3 g of tryptophan, and 0.2 g of histidine. Each supplement was prepackaged in a spherical tube. Participants were required to consume either the supplement or placebo twice per day for the entire 10-week training period. Participants in a.m./p.m. reported to the HPL on awakening and in the evening for their supplement. Participants in pre–post reported to the HPL immediately before their workout for their preexercise supplement and returned immediately after their workout for their postexercise supplement. On nonworkout days, participants in pre–post reported at a similar time of the day (as used for their workouts) for their supplement. After Friday's second supplement ingestion, participants received their weekend supply of protein. Participants were required to return all tubes to the HPL at the time of Monday's initial supplement ingestion. Compliance for protein ingestion was greater than 97% for the 10-week study.

Urine Measurements

Twenty-four-hour urine volumes were collected at Weeks 0 and 10 to assess urinary urea nitrogen excretion and determine nitrogen balance. Nitrogen balance was estimated using the following formula: nitrogen balance = total nitrogen intake – urinary urea nitrogen + 4 (Benotti & Blackburn, 1979; Isley, Underwood, & Chapman, 1983; Wright, 1980). All urinary urea nitrogen measures were determined with an Analox GM7 enzymatic metabolite analyzer (Analox Instruments USA, Lunenburg, MA). All samples were run in duplicate with a mean intra-assay variance of <5%.

Statistical Analysis

Statistical evaluation of the data was accomplished by a 3 (group) × 2 (time) repeated-measures analysis of variance. In addition, Δ Week 0 – Week 10 comparisons between groups in performance measures were analyzed with a one-way analysis of variance. In the event of a significant *F* ratio, least-significant-difference post hoc tests were used for pairwise comparisons. A criterion alpha level of $p \leq .05$ was used to determine statistical significance. All data are reported as *M* ± *SD*.

Results

Average daily dietary intakes for Weeks 0 and 10 are shown in Table 2. No significant changes in caloric intake ($p = .70$), carbohydrate intake ($p = .73$), or fat intake ($p = .73$) were seen in any group, and no differences between the groups in these measures were noted. A significant ($p < .05$) increase in daily protein intake (both absolute and relative to body mass) was seen in a.m./p.m. but not pre–post or control. Although participants in pre–post increased their relative protein intake by 20%, this change was not statistically different. The protein composition of the diet significantly increased ($p < .05$) at 10 weeks in both a.m./p.m. and pre–post, and the protein composition of their diets was significantly greater ($p = .01$) at this time point than seen in the control.

Urinary nitrogen excretion significantly increased ($p < .000$) from Week 0 (12.2 ± 5.5 g) to Week 10 (21.8 ± 11.2 g) in all groups, reflecting the greater demands of the training program. However, no between-groups differences were observed. In addition, participants in all groups were in positive nitrogen balance during both Week 0 (18.2 ± 12.6 g) and Week 10 (12.4 ± 12.3 g), and no significant differences ($p > .05$) between groups were seen.

Body-composition changes are shown in Table 3. No significant change in body mass occurred during the 10-week study in any group, and no differences between groups were observed ($p = .48$). In addition, no significant changes ($p > .05$) in percent body fat, fat mass, or lean body mass were seen in any group.

Table 2 Average Daily Dietary Intake

Variable	Group	Week 0	Week 10
kcal	a.m./p.m.	2,860 ± 864	2,862 ± 800
	pre–post	3,060 ± 1,258	2,738 ± 1,018
	control	2,904 ± 750	2,919 ± 533
kcal/kg body mass	a.m./p.m.	28.4 ± 9.2	28.6 ± 9.0
	pre–post	32.3 ± 13.2	28.6 ± 11.4
	control	30.5 ± 9.5	31.0 ± 8.9
Carbohydrate (g)	a.m./p.m.	275 ± 98	257 ± 85
	pre–post	327 ± 134	319 ± 124
	control	297 ± 81	291 ± 104
Protein (g)	a.m./p.m.	144 ± 34	229 ± 72*†
	pre–post	175 ± 102	204 ± 55
	control	157 ± 53	146 ± 49
Protein (g/kg)	a.m./p.m.	1.40 ± 0.22	2.28 ± 0.78*
	pre–post	1.80 ± 0.98	2.16 ± 0.67
	control	1.67 ± 0.70	1.58 ± 0.72
Fat (g)	a.m./p.m.	113 ± 72	100 ± 47
	pre–post	115 ± 63	81 ± 33
	control	115 ± 54	110 ± 35
% Carbohydrate	a.m./p.m.	41.0 ± 13.0	38.0 ± 15.2
	pre–post	47.2 ± 10.2	42.9 ± 8.0
	control	44.7 ± 15.5	44.1 ± 13.5
% Protein	a.m./p.m.	20.8 ± 4.7	31.5 ± 9.6*†
	pre–post	23.0 ± 7.5	31.6 ± 10.7*†
	control	24.5 ± 7.1	18.8 ± 3.6
% Fat	a.m./p.m.	32.1 ± 13.3	28.6 ± 11.0
	pre–post	27.6 ± 8.1	24.2 ± 4.9
	control	30.7 ± 15.6	31.0 ± 6.1

*$p < .05$, significant difference between Week 0 and Week 10. †$p < .05$, significantly different than control.

Significant improvements ($p < .05$) from Week 0 to Week 10 in 1RM squat were seen in all three groups (Figure 1), but significant improvements ($p < .05$) in 1RM bench press was seen in a.m./p.m. and pre–post only (Figure 2). However, no between-groups differences ($p > .05$) were seen, and Δ comparisons between groups showed no significant differences in either 1RM squat ($p = .67$) or 1RM bench press ($p = .85$).

Peak power in the squat exercise significantly increased ($p < .05$) from Week 0 to Week 10 in a.m./p.m. (1,341 ± 290 W vs. 1,503 ± 291 W, respectively) and pre–post (1,328 ± 245 W vs. 1,513 ± 355 W, respectively) but not in control (1,377 ± 230 W vs. 1,397 ± 116 W, respectively). Similarly, mean power in the squat exercise significantly increased ($p < .05$) from Week 0 to Week 10 in a.m./p.m.

Table 3 Anthropometric and Performance Changes During 10 Weeks of Protein Supplementation

Variable	Group	Week 0	Week 10
Body mass (kg)	a.m./p.m.	102.3 ± 18.9	102.0 ± 18.5
	pre–post	95.1 ± 14.4	96.3 ± 14.1
	control	100.1 ± 27.2	100.4 ± 27.7
Body fat (%)	a.m./p.m.	24.9 ± 10.2	23.0 ± 8.5
	pre–post	18.4 ± 6.3	18.0 ± 6.6
	control	21.7 ± 9.7	21.7 ± 8.2
Lean body mass (kg)	a.m./p.m.	75.1 ± 5.8	77.2 ± 6.4
	pre–post	77.1 ± 8.7	78.3 ± 8.2
	control	76.6 ± 13.3	77.0 ± 14.3
Fat mass (kg)	a.m./p.m.	27.2 ± 16.2	24.8 ± 13.3
	pre–post	18.0 ± 8.5	18.0 ± 8.9
	control	23.5 ± 17.0	23.4 ± 14.8

(692 ± 154 W vs. 756 ± 118 W, respectively) and pre–post (711 ± 113 W vs. 775 ± 149 W, respectively) but not in control (722 ± 73 W vs. 752 ± 88 W, respectively). No differences between the groups in either peak ($p = .88$) or mean power ($p = .98$) for the squat exercise were seen.

Peak power in the bench-press exercise significantly improved ($p < .02$) from Week 0 to Week 10 for pre–post only (683 ± 148 W vs. 733 ± 167 W, respectively); differences between Weeks 0 and 10 were not significant ($p > .05$) for a.m./p.m. (641 ± 178 W vs. 683 ± 149 W, respectively) or control (545 ± 132 W vs. 612 ± 126 W, respectively). No significant change ($p > .05$) in mean power was seen from Week 0 to Week 10 in the bench-press exercise for either a.m./p.m. (422 ± 107 W vs. 463 ± 84 W, respectively) or pre–post (474 ± 83 W vs. 483 ± 91 W, respectively), but a significant improvement ($p = .01$) was seen in control (398 ± 74 W vs. 463 ± 81 W, respectively). However, no significant differences ($p > .05$) between the groups in either peak or mean power for the bench-press exercise were observed. In addition, no significant differences ($p > .05$) in Δ comparisons between the groups were noted for any of the power measures in either the squat or the bench-press exercise.

Discussion

The findings of this study do not support the benefits of pre- and postexercise ingestion of a 42-g protein supplement compared with a morning and evening ingestion of the same protein supplement during 10 weeks of resistance training in resistance-trained men. Although both supplement groups significantly increased upper and lower body strength and power, no between-groups differences in any strength or power measure were seen. Furthermore, considering that no differences in strength and power performance were observed between control

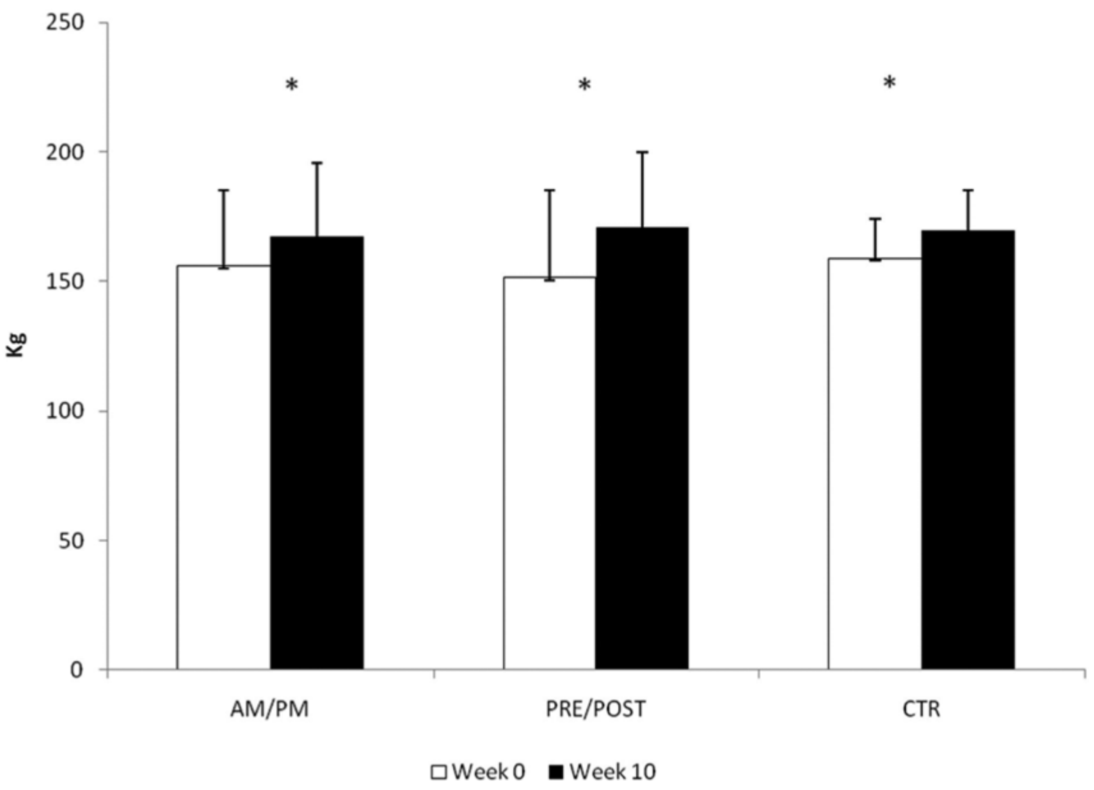

Figure 1 — 1-repetition squat performance. AM/PM = supplement provided in the morning and evening; PRE/POST = supplement provided immediately before and immediately after workouts; CTR = control. *$p < .05$ between Week 0 and Week 10.

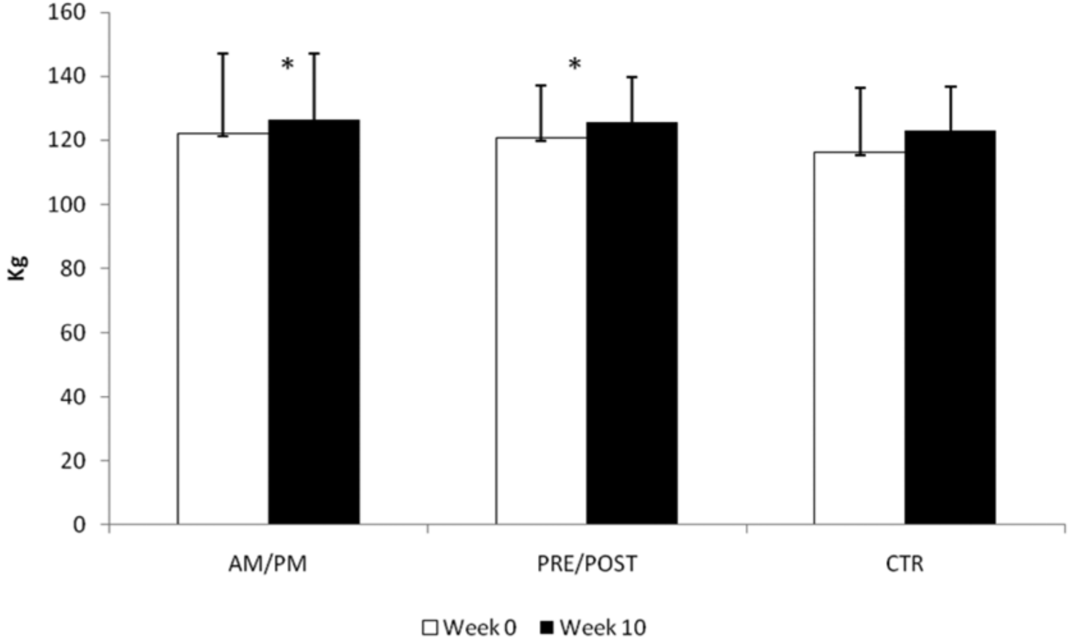

Figure 2 — 1-repetition bench-press performance. AM/PM = supplement provided in the morning and evening; PRE/POST = supplement provided immediately before and immediately after workouts; CTR = control. *$p < .05$ between Week 0 and Week 10.

and either of the protein-supplement groups, it appears that if dietary protein intake is at or exceeds recommended levels for a strength or power athlete (1.6 g/kg), the additional protein intake from a supplement, regardless of its timing, might not result in further performance gains. In addition, all groups were in positive nitrogen balance, indicating that protein intakes in this study were sufficient to meet the protein needs of these participants.

Previous studies in our laboratory demonstrated that protein intakes at or above the recommended levels for strength and power athletes do not augment lean body mass, power, or strength gains (Hoffman, Ratamess, Kang, Falvo, & Faigenbaum, 2006; Hoffman et al., 2007). The results from this study confirm those previous results and further indicate that the timing of protein-supplement ingestion does not provide any additional benefit for strength and power gains and lean-tissue accruement in resistance-trained athletes. However, the results of this study are also consistent with previous studies that demonstrated a trend toward greater strength improvements in resistance-trained participants with a daily protein intake greater than recommended levels for strength and power athletes (Hoffman et al., 2006). Although no significant differences were seen in comparisons between groups on strength and power performance, significant improvements in upper body strength and lower body power performance were seen in pre–post and a.m./p.m. only. In addition, examination of the six dependent performance variables revealed significant improvements over time in only two variables (1RM squat and mean power for the bench press) for control, whereas significant improvements in five of the six variables (1RM, peak power and mean power for the squat exercise, and 1RM and peak power for the bench-press exercise) were seen in pre–post and in four of six variables (1RM, peak power and mean power for the squat exercise, and 1RM for the bench-press exercise) in a.m./p.m. Considering that small, nonsignificant changes can have important practical significance for competitive athletes, results should be interpreted with appropriate context.

Previous studies have shown that ingesting protein or essential amino acids immediately before and/or after a resistance-exercise session can significantly increase rate of delivery and uptake of amino acids to skeletal muscle (Tipton et al., 2001) and increase muscle protein synthesis (Tipton et al., 2001, 2004). In addition, whey protein has been shown to be more effective than casein protein in stimulating muscle protein synthesis when provided immediately after a workout (Boirie et al., 1997). This is thought to be related to differences in amino acid composition (greater concentrations of leucine and isoleucine in whey than casein) and differences in digestive properties of whey and casein protein. Dangin et al. (2001) showed that the rate of absorption of a single serving of whey protein is significantly faster than that of a similar serving of casein protein. In consideration of these findings, several studies hypothesized that the timing of protein intake during a training regimen could provide a strategic benefit in maximizing muscle growth and performance (Andersen et al., 2005; Candow et al., 2006; Cribb & Hayes, 2006; Esmarck et al., 2001; Hulmi et al., 2008; Williams, van den Oord, Sharma, & Jones, 2001). Results from those studies, though, have not provided conclusive evidence to support this hypothesis. Although several studies have shown that protein intake close to an exercise session is important in maximizing muscle mass and strength gains (Andersen et al., Cribb & Hayes; Esmarck et al.; Hulmi et al.), other investigations have failed to support this hypothesis

(Candow et al.; Williams et al.). However, none of those studies examined experienced resistance-trained athletes. Participants were either recreationally trained or untrained. The current study appears to be the first to examine the effects of protein timing in experienced resistance-trained athletes.

Although the results of this study suggest that protein timing does not provide significant benefits to lean body mass and muscle-performance changes, this needs to be interpreted with some caution. Previous studies examining protein timing have generally used a supplement with greater carbohydrate content. Tipton et al. (1999, 2001), in their acute timing studies, generally used an amino-acid-to-carbohydrate ratio that was approximately 1:6, and in studies examining whole-protein intake the protein-to-carbohydrate ratio ranged from ~1:1 (Cribb & Hayes, 2006) to 1:0.7 (Esmarck et al., 2001). However, the precise ratio that elicits the most effective response is not known. It is likely that the carbohydrate content in protein supplements is important in facilitating transport across the intestinal lining and accelerates subsequent uptake by skeletal muscle by activating insulin-dependent transport mechanisms. In the current study, the ratio of protein to carbohydrate was 21:1. It is possible that the relatively small amount of carbohydrate in the supplement delayed the uptake of amino acids into muscle (presumably because of a lower insulin response), thereby missing a potential greater window of adaptation that might exist immediately after a training session.

Another potential limitation of this study was the relatively low caloric intake of the participants. The low energy intakes observed in this study are consistent with previous studies from our laboratory (Hoffman et al., 2006, 2007) and are supported by other studies that indicated that college athletes generally do not meet their nutritional and caloric needs (Cole et al., 2005; Hinton, Sanford, Davidson, Yakushko, & Beck, 2004). Caloric intake should exceed 44–50 kcal · kg body mass^{-1} · day^{-1} (American Dietetic Association, Dietitians of Canada, & American College of Sports Medicine, 2000), but the average caloric intake observed in this study (29.1 ± 9.7 kcal · kg body mass^{-1} · day^{-1}) was well below these recommended levels and might have affected the ability of these participants to tolerate high volumes of training that might have enabled them to elicit greater muscle size, power, and strength gains. Previous studies have demonstrated the importance of high energy intakes in eliciting significant gains in lean body mass (Roy, Fowles, Hill, & Tarnopolsky, 1997; Rozenak, Ward, Long, & Garhammer, 2002). Despite elevated protein intakes, the relatively low caloric intake likely limited gains in body mass and lean-tissue accruement. However, the elevated protein intakes might have provided an additional benefit for these athletes. Recently Pikosky et al. (2008) demonstrated that a high protein intake might offset the effects of an energy deficit. It is possible that despite relatively low energy intakes, the higher protein intake of all three groups might have prevented performance decrements.

In conclusion, results of this study do not support the hypothesis that protein timing provides a significant benefit to lean body mass, strength, and power improvements in experienced resistance-trained athletes. However, considering the relatively low carbohydrate content of the supplement and the low daily caloric intake of the participants, these results should be interpreted specifically to the parameters measured. Future research appears to be warranted to examine the effect of protein timing in experienced resistance-trained athletes with protein supplements with higher carbohydrate content and in participants with a much higher daily energy intake.

Acknowledgments

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References

American Dietetic Association, Dietitians of Canada, & American College of Sports Medicine. (2000). Position stand: Nutrition and athletic performance. *Medicine and Science in Sports and Exercise, 32,* 2130–2145.

Andersen, L.L., Tufekovic, G., Zebis, M.K., Crameri, R.M., Verlaan, G., Kjaer, M., et al. (2005). The effect of resistance training combined with timed ingestion of protein on muscle fiber size and muscle strength. *Metabolism: Clinical and Experimental, 54,* 151–156.

Benotti, P., & Blackburn, G.L. (1979). Protein and caloric or macronutrient metabolic management of the critically ill patient. *Critical Care Medicine, 7,* 520–525.

Boirie, Y., Dangin, M., Gachon, P., Vasson, M.P., Maubois, J.L., & Beaufrere, B. (1997). Slow and fast dietary proteins differently modulate postprandial protein accretion. *Proceedings of the National Academy of Sciences of the United States of America, 94,* 14930–14935.

Candow, D.G., Chilibeck, P.D., Facci, M., Abeysekara, S., & Zello, G.A. (2006). Protein supplementation before and after resistance training in older men. *European Journal of Applied Physiology, 97,* 548–556.

Cole, C.R., Salvaterra, G.F., Davis, J.E., Borja, M.E., Powell, L.M., Dubbs, E.C., et al. (2005). Evaluation of dietary practices of National Collegiate Athletic Association Division I football players. *Journal of Strength and Conditioning Research, 19,* 490–494.

Cribb, P.J., & Hayes, A. (2006). Effects of supplement timing and resistance exercise on skeletal muscle hypertrophy. *Medicine and Science in Sports and Exercise, 38,* 1918–1925.

Dangin, M., Boirie, Y., Garcia-Rodenas, C., Gachon, P., Fauquant, J., Callier, P., et al. (2001). The digestion rate of protein is an independent regulating factor of postprandial protein retention. *American Journal of Physiology. Endocrinology and Metabolism, 280,* E340–E348.

Esmarck, B., Andersen, J.L., Olsen, S., Richter, E.A., Mizuno, M., & Kjaer, M. (2001). Timing of postexercise protein intake is important for muscle hypertrophy with resistance training in elderly humans. *The Journal of Physiology, 535,* 301–311.

Hinton, P.S., Sanford, T.C., Davidson, M.M., Yakushko, O.F., & Beck, N.C. (2004). Nutrient intakes and dietary behaviors of male and female collegiate athletes. *International Journal of Sport Nutrition and Exercise Metabolism, 14,* 389–405.

Hoffman, J.R. (2006). *Norms for fitness, performance and health*. Champaign, IL: Human Kinetics.

Hoffman, J.R., Ratamess, N.A., Kang, J., Falvo, M.J., & Faigenbaum, A.D. (2006). Effect of protein intake on strength, body composition and endocrine changes in strength/power athletes. *Journal of the International Society of Sports Nutrition, 3,* 12–28.

Hoffman, J.R., Ratamess, N.A., Kang, J., Falvo, M.J., & Faigenbaum, A.D. (2007). Effects of protein supplementation on muscular performance and resting hormonal changes in college football players. *Journal of Sports Science, and Medicine, 6,* 85–92.

Hulmi, J.J., Kovanen, V., Selanne, H., Kraemer, W.J., Häkkinen, K., & Mero, A. (2008). Acute and long-term effects of resistance exercise with or without protein ingestion on muscle hypertrophy and gene expression. *Amino Acids*. Published online July.

Isley, W.L., Underwood, L.E., & Chapman, D.B. (1983). Dietary components that regulate serum somatomedin-C concentrations in humans. *The Journal of Clinical Investigation, 71,* 175–182.

Kraemer, W.J., Häkkinen, K., Newton, R.U., Nindl, B.C., Volek, J.S., McCormick, M., et al. (1999). Effects of heavy-resistance training on hormonal response patterns in younger vs. older men. *Journal of Applied Physiology, 87,* 982–992.

Kraemer, W.J., Ratamess, N.A., Volek, J.S., Häkkinen, K., Rubin, M.R., French, D.N., et al. (2006). The effects of amino acid supplementation on hormonal responses to overreaching. *Metabolism: Clinical and Experimental, 55,* 282–291.

Lemon, P.W., Tarnopolsky, M.A., MacDougal, J.D., & Atkinson, S.A. (1992). Protein requirements and muscle mass/strength changes during intensive training in novice bodybuilders. *Journal of Applied Physiology, 73,* 767–775.

Pikosky, M.A., Smith, T.J., Gredigain, A., Castaneda-Scheppa, C., Byerley, L., Glickman, E.L., et al. (2008). Increased protein maintains nitrogen balance during exercise-induced energy deficit. *Medicine and Science in Sports and Exercise, 40,* 505–512.

Rasmussen, B.B., Tipton, K.D., Miller, S.L., Wolf, S.E., & Wolfe, R.E. (2000). An oral essential amino acid-carbohydrate supplement enhances muscle protein anabolism after resistance exercise. *Journal of Applied Physiology, 88,* 386–392.

Ratamess, N.A., Kraemer, W.J., Volek, J.S., Rubin, M.R., Gomez, A.L., French, D.N., et al. (2003). The effects of amino acid supplementation on muscular performance during resistance training overreaching. *Journal of Strength and Conditioning Research, 17,* 250–258.

Roy, B.D., Fowles, J.R., Hill, R., & Tarnopolsky, M.A. (1997). Macronutrient intake and whole body protein metabolism following resistance exercise. *Medicine and Science in Sports and Exercise, 32,* 1412–1418.

Rozenek, R., Ward, P., Long, S., & Garhammer, J. (2002). Effects of high-calorie supplements on body composition and muscular strength following resistance training. *Journal of Sports Medicine and Physical Fitness, 42,* 340–347.

Tarnopolsky, M.A., Atkinson, S.A., MacDougal, J.D., Chesley, A., Phillips, S., & Shwarcz, H.P. (1992). Evaluation of protein requirements for trained strength athletes. *Journal of Applied Physiology, 73,* 1986–1995.

Tipton, K.D., Elliot, T.A., Cree, M.G., Wolf, S.E., Sanford, A.P., & Wolf, R.R. (2004). Ingestion of casein and whey proteins result in muscle anabolism after resistance exercise. *Medicine and Science in Sports and Exercise, 36,* 2073–2081.

Tipton, K.D., Ferrando, A.A., Phillips, S.M., Doyle, D., Jr., & Wolfe, R.R. (1999). Postexercise net protein synthesis in human muscle from orally administered amino acids. *American Journal of Physiology. Endocrinology and Metabolism, 276,* E628–E634.

Tipton, K.D., Rasmussen, B.B., Miller, S.L., Wolf, S.E., Owens-Stovall, S.K., Petrini, B.E., et al. (2001). Timing of amino acid-carbohydrate ingestion alters anabolic response of muscle to resistance exercise. *American Journal of Physiology. Endocrinology and Metabolism, 281,* E197–E206.

Williams, A.G., van den Oord, M., Sharma, A., & Jones, D.A. (2001). Is glucose/amino acid supplementation after exercise an aid to strength training? *British Journal of Sports Medicine, 35,* 109–113.

Willoughby, D.S., Stout, J.S., & Wilborn, C.D. (2007). Effects of resistance training and protein plus amino acid supplementation on muscle anabolism, mass and strength. *Amino Acids, 32,* 467–477.

Wright, R.A. (1980). Nutritional assessment. *Journal of the American Medical Association, 244,* 559–560.