

# Creatine supplementation during resistance training in college football athletes

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## ABSTRACT

BEMBEN, M. G., D. A. BEMBEN, D. D. LOFTISS, and A. W. KNEHANS. Creatine supplementation during resistance training in college football athletes. *Med. Sci. Sports Exerc.*, Vol. 33, No. 10, 2001, pp. 1667–1673. **Purpose:** This investigation assessed the effects of a 9-wk regimen of creatine monohydrate ( $\text{Cr} \times \text{H}_2\text{O}$ ) supplementation coupled with resistance training on body composition and neuromuscular performance in NCAA Division I football athletes. **Methods:** Twenty-five subjects were randomly assigned in a double-blind, randomized placebo-controlled design, to a treatment ( $\text{Cr}$ ,  $N = 9$ ), placebo ( $\text{P}$ ,  $N = 8$ ), or control group ( $\text{C}$ ,  $N = 8$ ). The  $\text{Cr}$  group received  $20 \text{ g} \cdot \text{d}^{-1}$  of creatine for the first 5 d in 5-g doses, four times daily, followed by  $5 \text{ g} \cdot \text{d}^{-1}$  for the remainder of the study. Each 5-g dose was mixed with 500 mL of glucose solution (Gatorade®). The  $\text{P}$  group received a placebo (sodium phosphate monohydrate;  $\text{NaH}_2\text{PO}_4 \times \text{H}_2\text{O}$ ) following the exact protocol as the  $\text{Cr}$  group. The  $\text{C}$  group received no supplementation. All subjects resistance trained  $4 \text{ d} \cdot \text{wk}^{-1}$ . Measurements of neuromuscular performance and body composition were made pre- and post-training after supplementation while monitoring dietary intakes. **Results:** Repeated measures ANOVA indicated significant differences occurred between the  $\text{Cr}$  group and the other two groups ( $\text{P}$  and  $\text{C}$ ) for total body weight, lean body mass, cell hydration, strength, peak torque at  $300^\circ \cdot \text{s}^{-1}$  knee flexion, percent torque decrement, and anaerobic power and capacity. However, percent body fat, peak torque during both knee flexion and extension at 60 and  $180^\circ \cdot \text{s}^{-1}$ , peak torque at  $300^\circ \cdot \text{s}^{-1}$  during knee extension, global muscular strength (power clean), and extracellular fluid remained statistically unchanged for all groups. **Conclusions:** Our findings indicate that creatine, supplemented concurrently with resistance and anaerobic training, may positively affect cell hydration status and enhance performance variables further than augmentation seen with training alone. **Key Words:** SUPPLEMENTATION, MUSCLE PERFORMANCE, ERGOGENIC AIDS, CELL HYDRATION

In competitive athletics, techniques for performance augmentation are continuously being assessed and reassessed in search of the optimal training method. With increased awareness surrounding unsafe and illegal methods, such as the use of steroids, athletes and individuals responsible for training these athletes are turning to nutritive supplementation in an attempt to enhance or maximize performance capabilities. Creatine ( $\text{Cr} \times \text{H}_2\text{O}$ ) supplementation is one form of ergogenic aid that has gained popularity as a supplement to resistance-training programs.

Creatine is an amino acid derivative [ $\alpha$ -methylguanidino) acetic acid] that occurs naturally to a small extent in the human body. Approximately 2% of total body  $\text{Cr}$  is synthesized in the liver, pancreas, and kidneys, and about 60% of the  $\text{Cr}$  found in the body is in the form of creatine phosphate (CP) (17). Found primarily in skeletal muscle, creatine in its free ( $\text{Cr}$ ) and phosphorylated forms (CP) plays a crucial role in skeletal muscle energy metabolism. The theoretical premise behind  $\text{Cr}$  supplementation is threefold. First, increased intramuscular stores of  $\text{Cr}$  may help maintain high cellular ATP/ADP ratios (5,19). This is accomplished by the creatine kinase reaction ( $\text{CP} + \text{ADP} + \text{H}^+ \leftrightarrow$

$\text{ATP} + \text{Cr}$ ) by which ADP is rephosphorylated back to ATP (18,34). Second, CP also acts to buffer accumulating protons ( $\text{H}^+$ ), which would also potentiate the continuation of maximal exertion (18). Finally,  $\text{Cr}$  may facilitate energy translocation from the mitochondria to the various sites of ATP utilization by a process termed the creatine phosphate energy shuttle (18,34). It seems reasonable to suggest that the attenuation of ATP degradation by the phosphorylation of ADP would enable an individual to sustain force production longer per given work task during training, resulting in a greater overload to the musculoskeletal system, thus maximizing the adaptive function of skeletal muscle (7).

A number of studies have examined  $\text{Cr}$  supplementation and have demonstrated enhanced performance (4,7,12,14,15,21,23–25,27) although others have shown no statistically significant effects of the supplementation (23,31). It seems reasonable to expect that football athletes could benefit from  $\text{Cr}$  supplementation because most of their on field activity involves explosive, powerful anaerobic movements that require the immediate release of energy provided by ATP and the quick resynthesis of ATP from ADP and CP. Therefore, the purpose of this study was to assess the effects of 9 wk of creatine monohydrate supplementation and a concomitant anaerobic resistance training and conditioning program on body composition and neuromuscular performance in NCAA Division I redshirt football players.

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## METHODS

**Subjects.** Twenty-five male, NCAA Division I-A red-shirt football players aged 18–22 yr, from the University of Oklahoma (OU) volunteered for this study. The use of the term “redshirt” in this particular study indicated that these subjects were true, incoming freshmen who were allowed to train and practice with the entire team but were not able to compete in actual games during the regular season. Before being allowed to participate in the study, athletes were questioned regarding previous and/or current use of any ergogenic aids. All participants were also subject to random drug testing throughout the study period from both the University of Oklahoma and the NCAA. Approval for the use of human subjects was given by the Institutional Human Subject Review Board, and written informed consent was obtained from all subjects before the pretesting period.

**Creatine supplementation.** The design of this study was double blind, randomized, and placebo controlled, with subjects being randomly assigned into one of three groups: treatment (Cr;  $N = 9$ ; mean age =  $19.4 \pm 0.1$  yr; mean height =  $179.9 \pm 3.3$  cm; mean weight =  $89.2 \pm 6.6$  kg), placebo (P;  $N = 8$ ; mean age =  $19.3 \pm 0.5$  yr; mean height =  $184.1 \pm 2.0$  cm; mean weight =  $91.3 \pm 4.4$  kg), or control (C;  $N = 8$ ; mean age =  $19.0 \pm 0.3$  yr; mean height =  $187.9 \pm 2.7$  cm; mean weight =  $95.7 \pm 7.3$  kg). The treatment group (Cr) received 5 g of creatine in the form of creatine monohydrate four times daily, separated by 3–4 h ( $20 \text{ g} \cdot \text{d}^{-1}$ ) for the first five days of the study and 5 g once a day (maintenance dose) for the duration of the study. No side effects have been reported with creatine supplementation because it has a low molecular weight (149.15) that allows for its safe, nontoxic removal by the kidneys by the non-energy-dependent process of diffusion (10,20,23,25,26). The group randomly assigned to the placebo group received a placebo in the form of a 500-mL glucose solution (Gatorade®) containing sodium phosphate, which has a similar appearance to the treatment supplement and was consumed immediately within 1 min of mixing. The control group received no supplement.

**Preseason training program.** All subjects were involved in a progressive resistance-training program and metabolic conditioning regimen for the entire 9-wk study. This preseason training program was designed as a 4-d-wk<sup>-1</sup> split routine and developed specifically for the football program. All members of the football team trained with this same program, not only the subjects used in the study. The resistance program was designed using the concept of periodization and focused primarily on the development of strength, power, and increased lean body mass. On any given day, workouts consisted of approximately 10 upper or lower body lifts, which included large muscle mass, multi-joint exercises such as the leg press, bench press, and power clean, as well as supplemental single-joint movements such as bicep curls, hamstring curls, and quad-ri-cep extensions.

Specifically, days 1 (Monday) and 2 (Tuesday) of a given week were primarily focused on strength development, whereas days 3 (Thursday) and 4 (Friday) were focused on

power development. Wednesday was a rest day. Day 1 incorporated lifts for the lower body (squat, power clean, leg extensions, leg curls, dead lift, etc.) and back (pull ups, lat pulls, one-arm dumbbell rows, etc.), whereas day 2 involved the upper body (bench press, incline press, push-press, upright rows, flys, power snatches, etc.). Both of these days utilized three to five sets of 8–12 repetitions at loads of 75–105% 1RM. Days 3 and 4 involved the same muscle groups and lifts but focused on power development by utilizing a program of three to five sets of two to four repetitions at loads of 65–95% 1RM. Each lifting session was about 75 min in length. The metabolic conditioning involved approximately 45 min of middle-distance interval training, 400-m sprints, and Fartlek training on Mondays and Thursdays and plyometric and agility training on Wednesdays and Fridays. Subjects were required to attend all lifting sessions to remain in the subject pool. Workout compliance was monitored on a daily basis by the strength and conditioning staff and research team, and those individuals missing more than three workouts during the course of the study were eliminated from the subject pool.

**Testing schedule.** The study began with subjects reporting to the laboratory having abstained from strenuous physical activity for at least 48 h and having fasted for at least 5 h. Subjects then proceeded to be tested for all physiological parameters during the next 5 d. Measurements made during this period were used as baseline values for comparison with a subsequent final visit 9 wk later.

**Dietary records.** Daily dietary intakes were estimated during the 9-wk treatment period using 1-d dietary records before each data collection period. Food records were analyzed for nutrient and mineral content using Nutritionist IV® software. Dietary consumption for the supplementation period was also monitored by a registered dietician overseeing daily varsity athletic training table meals, and any significant dietary deviations for any of the subjects during the course of the study was documented.

**Neuromuscular strength.** This portion of the testing was completed at the University of Oklahoma Strength and Conditioning Complex under the direct supervision of the principle investigator and the OU conditioning staff. The subjects were tested to determine muscular strength using the one-repetition maximum (1RM) for the bench press, squat, and power clean to assess absolute upper and lower body strength and global muscular strength respectively. The 1RM for each lift was reached within five attempts, after a brief warm-up of five to eight repetitions with loads of approximately 50% of the anticipated 1RM. Three to five minutes separated each attempt during the 1RM process. All strength testing followed the same progression (bench press, squat, power clean) for both the pre- and post-testing sessions, and each test was separated by an adequate recovery period of at least 10 min. All lifts followed standardized procedures that each athlete used and was monitored by the staff.

**Anaerobic power and capacity.** Tests of anaerobic capacity provide information concerning the ATP-PC and glycolytic energy systems ability to resynthesize ATP. The

TABLE 1. Effects of Cr supplementation and anaerobic training on body composition.

Group	BW <sup>T,1</sup> (kg)	LBM <sup>T,1</sup> (kg)	CLBM <sup>T,1</sup> (kg)	%Fat	%CFat	ICF <sup>T,1</sup> (L)	ECF (L)	TBW <sup>T,1</sup> (L)
Creatine								
Pre	89.2 ± 6.6	77.1 ± 4.2	81.1 ± 5.5	12.6 ± 1.9	11.6 ± 2.1	36.7 ± 3.1	23.5 ± 1.8	60.2 ± 4.5
Post	92.3 ± 7.2	80.0 ± 5.0	84.8 ± 6.0	12.2 ± 1.6	11.4 ± 2.5	40.0 ± 3.1	23.5 ± 1.9	63.4 ± 4.7
% Δ	+3.5	+3.8	+4.6	-3.2	-1.7	+9.0	NC	+5.3
Placebo								
Pre	91.3 ± 4.4	78.2 ± 2.2	77.5 ± 2.1	13.9 ± 2.5	14.4 ± 2.7	33.4 ± 1.9	21.8 ± 0.6	56.6 ± 1.5
Post	91.9 ± 4.2	78.0 ± 2.2	77.0 ± 2.5	14.9 ± 2.5	15.6 ± 2.5	33.1 ± 1.6	21.9 ± 0.8	56.1 ± 1.6
% Δ	NC	NC	NC	+7.2	+8.3	NC	NC	NC
Control								
Pre	95.7 ± 7.3	77.9 ± 2.5	76.1 ± 3.2	13.3 ± 3.1	9.3 ± 2.5	33.0 ± 2.1	23.8 ± 2.3	57.2 ± 3.7
Post	95.9 ± 6.7	78.6 ± 2.3	76.7 ± 3.6	13.2 ± 3.0	9.2 ± 2.4	33.4 ± 2.2	23.9 ± 2.2	57.3 ± 3.2
% Δ	NC	NC	NC	NC	-1.1	+1.2	NC	NC

BW, body weight; LBM, lean body mass; CLBM, corrected LBM; %Fat, percent fat; %CFat, corrected percent fat; ICF, intracellular fluid; ECF, extracellular fluid; TBW, total body water.

<sup>T</sup> Significant trial effect ( $P < 0.05$ ).

<sup>1</sup> Significant group by trial interaction ( $P < 0.05$ ).

NC, no change (if less than  $\pm 1.0\%$  change).

Wingate anaerobic bicycle test required the subjects to pedal a bicycle ergometer as fast as possible against a resistance equal to  $0.075 \text{ kg} \times \text{body weight}$  for 30 s (3). The peak number of pedal revolutions in any 5-s interval was used to calculate peak power, whereas the total number of revolutions produced during the entire 30 s was used to calculate anaerobic capacity.

**Isokinetic peak torque.** Isokinetic strength (peak torque) was determined for the quadriceps and hamstring muscle groups of the right leg at speeds of  $60^\circ$ ,  $180^\circ$ , and  $300^\circ \cdot \text{s}^{-1}$  with the aid of a Cybex II Isokinetic Dynamometer® (Medway, MA). Additionally, the percent torque decrement for the right leg quadriceps muscle group was assessed using the standardized Thorstensson and Karlsson fatigue test (32), which consisted of 50 consecutive maximal quadriceps extensions at  $180^\circ \cdot \text{s}^{-1}$ .

**Body composition.** Body composition was assessed to document changes in fat free body mass, fat mass, total body water, and intracellular and extracellular water that might be attributed to the addition of creatine supplementation. The assessment of body composition was done using hydrodensitometry both before and immediately after the 9-wk supplementation period. All subjects were weighed hydrostatically in the morning after fasting overnight. Each subject was asked to perform a complete exhalation while being submerged in water resting only on a body support carriage, the weight of which was accounted for and recorded as the "tare" weight before the test. The subject was given at least six trials to produce the heaviest underwater weight possible, recorded in pounds and converted to kilograms to be used in estimating body density. Vital lung capacity was measured using a Single Breath Wedge Spirometer (Vitalograph 122000, Hans Rudolph Inc., Kansas City, MO), and functional residual lung volume (RV) was estimated by using 0.24 multiplied by vital capacity. The largest of three separate trials was recorded for each subject. Although direct measurement of residual lung volumes is preferred, an error of only  $0.003 \text{ g} \cdot \text{cm}^{-3}$  has been documented using the aforementioned estimation technique (28). Percent body fat was estimated using body density (29).

Total body water, as well as intra- and extra-cellular water, were assessed using a Multifrequency Bioimpedance

Spectrum Analyzer System (Xitron Technologies, Inc., San Diego, CA) (1,6,22,33,37). Subjects were tested in the morning before eating or engaging in any physical activity to try and eliminate any influences that might affect measurements.

**Statistical analysis.** All data were reported as means  $\pm$  SE. All statistical analysis was performed using SPSS (v 9.0.1). Descriptive statistics for the dependent variables were computed using SPSS means procedure. Dependent  $t$ -tests were used to compare water values for the two trials during the pretesting and again during the posttesting sessions to determine within day reliability for this procedure. A repeated measures ANOVA (Group  $\times$  Trial) was then used to determine whether differences existed between groups or trials and the possible existence of a group by trial interaction for each parameter of interest. The Bonferroni  $t$ -statistic procedure was used to adjust the overall alpha level based on the number of multiple comparisons performed to minimize the Type I error rate. Statistical significance for all data was set at  $P \leq 0.05$ .

## RESULTS

Thirty subjects initially were recruited to participate in this study, but attrition due to injuries or compliance failure with the training or testing protocols resulted in the loss of five subjects. The average age for the participants was  $19.2 \pm 0.3$  yr, and there were no statistical differences between the three groups concerning standing height or body weight at the beginning of this study. There were also no statistical differences between the groups regarding nutrient intakes before or after the training. Caloric intakes increased for all three groups after the 9 wk of training from an average of 3044 kcal to 4231 kcal, but the percentages of energy nutrients attributed to carbohydrates, proteins, and fats remained constant (45%, 15%, and 36%, respectively).

**Body composition.** Repeated measures ANOVA indicated no significant group effects for any of the parameters of interest, but there were significant trial and group by trial effects for body weight, lean body mass as determined by underwater weighing, lean body mass corrected for total body water, intracellular fluid, and total body water (Table 1.).

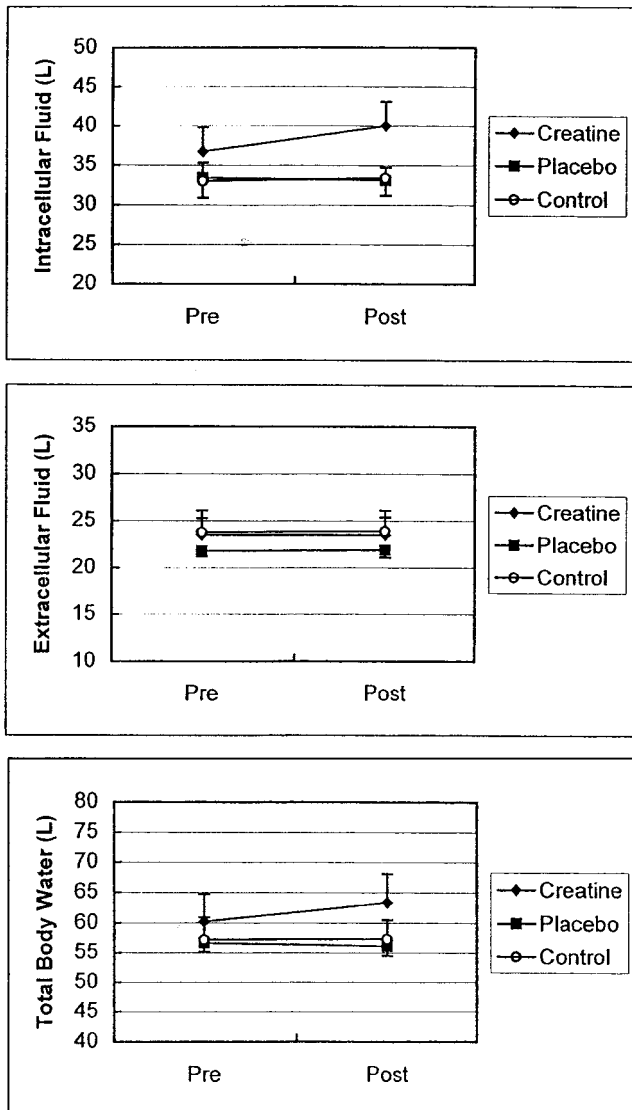


FIGURE 1—Changes in body water as measured by multi-frequency bioelectric spectroscopy (Xitron®) after the 9-wk intervention for the treatment (Cr), placebo (P), and control (C) groups. The top panel represents changes in intracellular fluid (L), the middle panel extracellular fluid (L), and the bottom panel total body water.

Body weight in kilograms increased by an average of 3.5% and lean body mass by 3.8% (4.6% when LBM was corrected for TBW) for the Cr group after the intervention, whereas there was essentially no change for the same three variables for both the P and C groups. There were no statistically significant differences for the measures of percent fat from underwater weighing or percent fat when corrected by TBW, with a small decrease in fat for the Cr group (−3.2%), an increase in the P group (+7.2%), and no change for the C group.

TBW was increased by an average of 5.3% for the Cr group with no changes for the other two groups (significant trial and group by trial effects), whereas there were no changes in ECF for any of the three groups (Fig. 1.). Similar to the changes in TBW, there were significant trial and group by trial interactions for ICF, with the Cr group increasing by an average of 9% with either no change in ICF for the P group and a small increase of 1.2% for the C group.

**Dynamic muscular strength and anaerobic power.** Table 2 depicts the effects of the Cr supplementation and the anaerobic training protocols on bench press strength, power clean strength, squat strength, anaerobic power, anaerobic capacity, and percent decrement in anaerobic capacity. There were no significant differences between the groups; however, there were significant trial and group by trial effects for squat strength, anaerobic power, and anaerobic capacity. In general, strength improved for the Cr group for all three lifts (bench press, power clean, and squat) with increases of 5.2%, 3.8%, and 8.7%, respectively. The C group had essentially no change after training for the same three exercises, whereas the P group had small improvements of 1.9% for the power clean and 5.1% for the squat (Fig. 2).

Anaerobic power and anaerobic capacity, both determined by the Wingate bicycle ergometer test, improved dramatically for the Cr group (19.6% and 18.4%, respectively), whereas little or no change was evidenced by the other two groups after the training program. Finally, the Cr group had a 15.9% improvement in the Thorstensson and Karlsson isokinetic test, which expresses the amount of torque decrement that occurs after 50 consecutive maximal quadriceps extensions at a speed of  $180^{\circ}\cdot\text{s}^{-1}$ , whereas both the P and C groups had larger torque deficits for this test of 7.1% and 11.0%, respectively, after completion of the training program (Fig. 3).

**Isokinetic muscular performance.** Table 3 depicts the changes in peak torque for the quadriceps and hamstring muscle groups at slow ( $60^{\circ}\cdot\text{s}^{-1}$ ), moderate ( $180^{\circ}\cdot\text{s}^{-1}$ ), and fast speeds ( $300^{\circ}\cdot\text{s}^{-1}$ ). There were no significant group effects for any of the muscle groups or speeds and no significant trial or group by trial effects for any of the muscle groups or speeds with the exception of the peak torque for the hamstrings at  $300^{\circ}\cdot\text{s}^{-1}$ . The Cr group had an average increase in peak torque at  $300^{\circ}\cdot\text{s}^{-1}$  of 17.6%, whereas the P group decreased by an average of 5.5% and the C group exhibited no change.

## DISCUSSION

The purpose of this study was to assess the effects of 9 wk of creatine monohydrate supplementation and a concomitant anaerobic training program for NCAA Division I redshirt football athletes. This specific athletic population was chosen due to the integral role Cr plays in facilitating the ability of the ATP-PC energy system to provide energy for intense muscular contractions needed for short, explosive bursts of movement so common in football.

Our data indicate that there were significant increases in body weight and lean body mass for the treatment group (Cr) when compared with the other two groups after the training program, with little or no change in the percentage of body fat. These findings are consistent with numerous other studies (2,4,8,12,14,20,21,30,35,36). However, one unique aspect of this study is the ability to try and define the mechanism responsible for an increased lean body mass by the measurement of body water. The increase in body

TABLE 2. Effects of Cr supplementation and anaerobic training on strength, anaerobic power, anaerobic capacity, and percent decrement in anaerobic capacity.

Group	Bench Press <sup>1</sup> (kg)	Power Clean (kg)	Squat <sup>1,†</sup> (kg)	An. Power <sup>T,†</sup> (W)	An. Cap <sup>T,†</sup> (W)	%Dec <sup>T,†</sup> (N·m)
Creatine						
Pre	131.8 ± 9.6	110.1 ± 4.4	210.1 ± 11.0	1021.3 ± 75.6	727.6 ± 35.3	94.4 ± 4.1
Post	138.6 ± 10.5	114.3 ± 4.9	228.3 ± 12.1	1221.5 ± 52.2	861.6 ± 39.3	79.4 ± 7.3
% Δ	+5.2	+3.8	+8.7	+19.6	+18.4	-15.9
Placebo						
Pre	132.1 ± 7.6	104.4 ± 3.4	190.1 ± 11.2	1135.7 ± 46.7	797.8 ± 33.3	80.2 ± 6.7
Post	132.4 ± 8.5	106.4 ± 3.4	199.7 ± 10.6	1152.4 ± 37.6	804.5 ± 36.0	85.4 ± 5.3
% Δ	NC	+1.9	+5.1	+1.5	NC	+7.1
Control						
Pre	126.7 ± 5.8	105.6 ± 4.6	202.8 ± 10.2	1160.4 ± 80.5	783.4 ± 34.8	80.9 ± 9.2
Post	125.3 ± 4.6	105.6 ± 4.5	204.0 ± 10.1	1168.1 ± 80.2	803.3 ± 29.4	89.8 ± 2.6
% Δ	-1.1	NC	NC	NC	+2.5	+11.0

<sup>†</sup> Significant trial effect ( $P < 0.05$ ).

<sup>1</sup> Significant group by trial interaction ( $P < 0.05$ ).

NC, no change (if less than  $\pm 1.0\%$  change).

weight and lean mass found in this study may be explained by muscle hypertrophy and increases in total body water, compartmentalized as intracellular fluid. This increase in

intracellular fluid, with little or no change in extracellular fluid is supported by recent studies (20,21,24,37). It can be speculated that creatine osmotically draws water into the

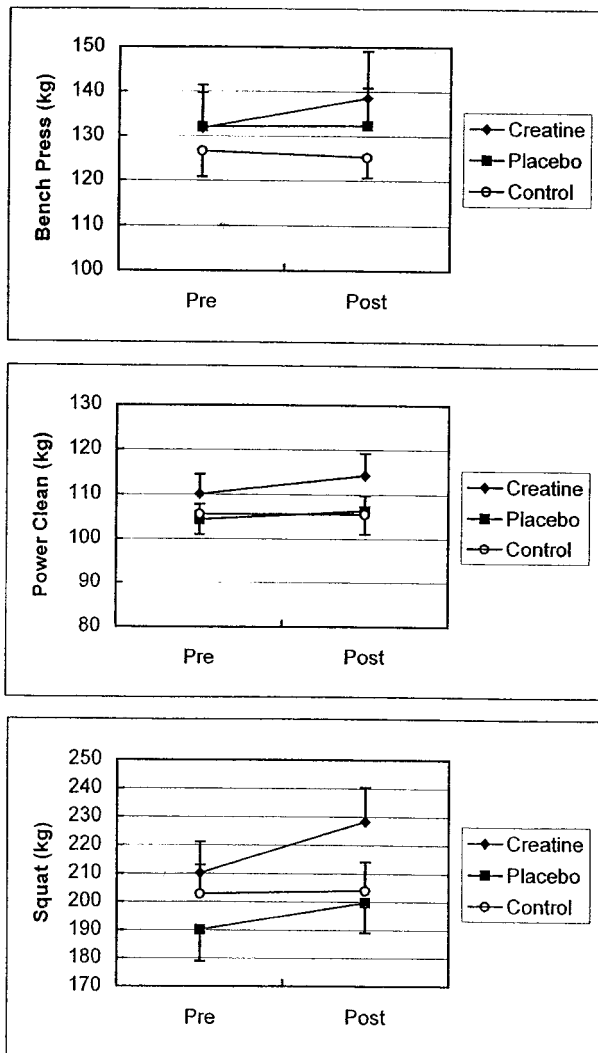


FIGURE 2—Changes in strength and power as measured by the bench press, power clean, and squat lifts after the 9-wk intervention for the treatment (Cr), placebo (P), and control (C) groups. The top panel represents changes in bench press strength (kg), the middle panel power clean (kg), and the bottom panel squat strength (kg).

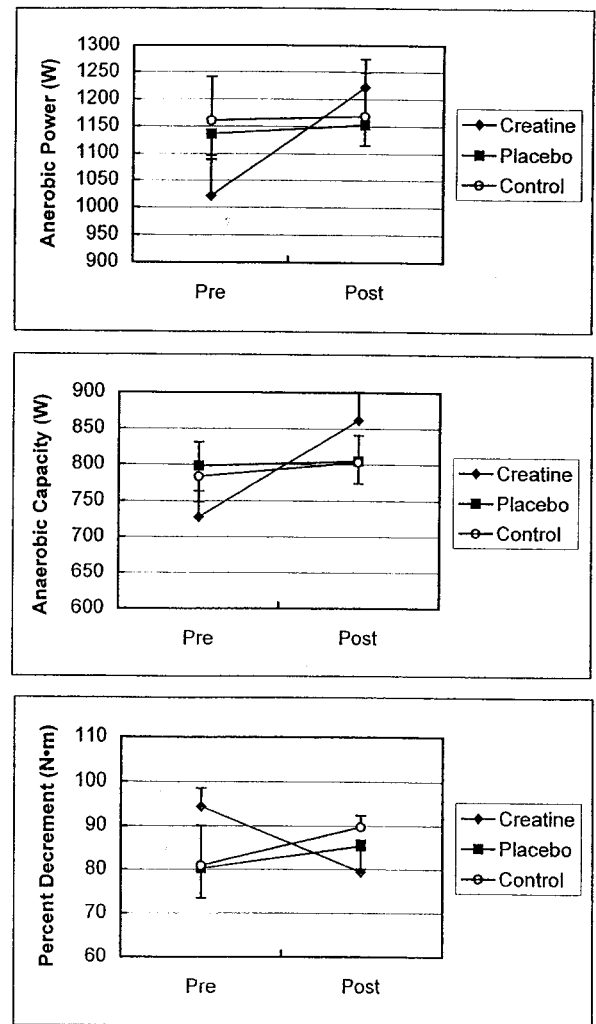


FIGURE 3—Changes in anaerobic power and capacity as measured by the Wingate bicycle ergometer test and percent force decrement as measured by the Cybex® II isokinetic dynamometer after the 9-wk intervention for the treatment (Cr), placebo (P), and control (C) groups. The top panel represents changes in anaerobic power (W), the middle panel anaerobic capacity (W), and the bottom panel percent decrement in torque (N·m).

TABLE 3. Effects of Cr supplementation and anaerobic training on isokinetic torque (N·m) produced at 60, 180, and 300°·s<sup>-1</sup>.

Group	Quad PT 60°·s <sup>-1</sup>	Quad PT 180°·s <sup>-1</sup>	Quad PT 300°·s <sup>-1</sup>	Ham PT 60°·s <sup>-1</sup>	Ham PT 180°·s <sup>-1</sup>	Ham PT 300°·s <sup>-1</sup>
Creatine						
Pre	227.8 ± 14.8	150.3 ± 14.1	100.3 ± 6.1	147.1 ± 11.3	106.3 ± 8.3	74.6 ± 6.0
Post	221.9 ± 15.8	159.5 ± 13.0	113.9 ± 12.2	140.9 ± 10.0	105.2 ± 6.5	87.7 ± 7.7
% Δ	-2.6	+6.1	+13.6	-4.2	-1.0	+17.6
Placebo						
Pre	250.1 ± 12.8	157.3 ± 8.9	101.7 ± 6.2	145.2 ± 9.3	105.2 ± 7.1	79.7 ± 4.8
Post	251.6 ± 14.2	162.9 ± 6.6	105.6 ± 6.3	145.2 ± 7.8	105.7 ± 5.7	75.3 ± 3.9
% Δ	NC	+3.6	+3.8	NC	NC	-5.5
Control						
Pre	275.7 ± 14.0	158.3 ± 8.9	102.2 ± 5.8	172.4 ± 7.9	132.4 ± 5.6	91.0 ± 5.5
Post	272.9 ± 7.9	167.1 ± 8.4	103.7 ± 6.2	153.9 ± 8.4	120.2 ± 8.2	91.8 ± 4.8
% Δ	-1.0	+5.7	+1.5	-10.7	-9.2	NC

<sup>†</sup> Significant trial effect ( $P < 0.05$ ).

<sup>‡</sup> Significant group by trial interaction ( $P < 0.05$ ).

NC, no change (if less than ±1.0% change).

intracellular compartment and may then potentiate protein and glycogen synthesis (16).

The improvements in strength and power documented for the treatment group (Cr) may be due to a greater volume of training over the 9-wk training intervention when compared with the other two groups. As other authors have suggested, Cr supplementation may allow for quicker resynthesis of ATP from ADP after short-term intense exercise, which would then allow the individual higher quality bouts of repeated exercise with less decrement in performance (2,8,11,13,23,30,35). This would help explain the larger increases in strength (bench press, power clean, and squat) and power for the Cr group. However, some studies have reported that Cr supplementation had no additional benefits when compared with training alone, but this may be due to the different performance tasks used to evaluate muscular performance, the use of untrained subjects, a potential placebo effect, or weak statistical power because of small sample sizes (9,23,31). It is important to remember that the present study incorporated a placebo group, as well as a control group, to help explain the possibility of a “placebo effect” and the sample sizes for the three groups were consistent with most training programs. It should also be mentioned that another possibility for the improved neuromuscular performance, i.e., increased strength and power, is a greater high-energy liberation for greater strength and enhanced cross-bridge cycling for improved power. Finally, another factor to consider when examining these data is the fact that the subjects used in this study were already well trained and accustomed to high-effort training; therefore, any increase in training volume due to the creatine supple-

mentation might reflect a fairly substantial improvement in neuromuscular performance.

The lack of improvement in isokinetic muscle performance has not been as well documented. In one of the few studies that used isokinetic torque production as the outcome parameter after Cr supplementation, Gilliam et al. (9) reported no ergogenic effect of the supplementation. Unfortunately, this study failed to include a control group and subjects performed no training between pre- and post-testing sessions. It is difficult to explain the lack of improvement in torque production in the current study other than the fact that there would be a loss of specificity regarding the different types of contractions occurring between the training program and the testing procedure.

In conclusion, our data suggest that creatine supplementation is a viable ergogenic aid that probably enhances the ATP-PC system and allows for a quicker recovery from fatiguing exercise and enables an individual to perform more exercise in a given period of time. Furthermore, Cr may act indirectly by increasing the hydration status of the muscle cell by creating an osmotic draw of water into the cell and stimulating protein synthesis.

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