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The Effect of Creatine Supplementation During Resistance Training in Women

MEGAN BRENNER, JANET WALBERG RANKIN, AND DON SEBOLT

Department of Human Nutrition, Foods, and Exercise, Virginia Tech, Blacksburg, VA 24061-0351.

ABSTRACT

Sixteen collegiate women lacrosse players consumed either creatine (C, $n = 7$) or a placebo (P, $n = 9$) for 5 weeks during their preseason conditioning program (20 g · d^{-1} for 1 week and 2 g · d^{-1} for 4 weeks). Pre- and posttesting consisted of body composition, muscle endurance test, blood lactate response to the endurance test, 1 repetition maximum (1RM) bench press and leg extension, and blood glutamyltransferase (GGL) and blood urea nitrogen (BUN). Testing revealed that 1RM bench press significantly increased in both groups, with the C group improving significantly more than the P group (6.2 ± 2.0 and 2.8 ± 1.8 kg). Percent body fat by skinfold decreased significantly more in C than the P group (−1.2 ± 0.9 and 0.3 ± 0.8), but was not different by group by hydrodensitometry. No significant differences between groups were found for all other measures, but significant time effects were noted for body weight gain (0.5 ± 3.2 kg), 1RM leg extension (1.4 ± 4.1 kg), BUN (0.07 ± 0.03 mmol · L^{-1}), total work during the muscle endurance test (283.5 ± 387.3 watts), and fat-free mass by skinfold (0.7 ± 1.2 kg). In summary, a regime of dietary creatine supplementation significantly improved upper-body strength gain and decreased the percent body fat as assessed by skinfold in women athletes engaged in a resistance-training program.

Key Words: muscle strength, muscle endurance, lactate

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Introduction

Previous research has demonstrated that oral creatine supplementation of 20 g · d^{-1} for 6 days increased the total creatine content of the muscle about 20% in men and maintained this level with ingestion of 2 g · d^{-1} thereafter (10). Since creatine phosphate plays a role in anaerobic generation of ATP, this dietary supplement has been tested to determine whether it can improve performance in high-intensity exercise. Most studies using maximal, single-sprint tests have not found a benefit of short-term creatine supplementation (3, 4, 16, 19, 22). However, a few studies have reported enhancement of performance of maximal efforts, including a single sprint (15) and maximal isometric muscle strength (14), with less than 1 week of supplementation. Many studies have identified an ergogenic effect of brief creatine consumption periods on maximal effort, repeated sprint exercise (1, 7, 9, 23).

Many of these studies have provided creatine for less than 7 days. Since athletes typically consume creatine throughout their season, it is of interest to know whether longer-term creatine consumption will enhance the effects of training. Harris et al. (8) reported that the increase in muscle creatine as a result of oral supplementation was greater in the leg that was trained on an ergometer as compared to the control, rested leg. This interaction between training and oral creatine on muscle phosphagen changes has not been validated with resistance training. However, several studies have been conducted to determine whether oral creatine affects muscle performance changes due to resistance training. Studies using male football players (13, 18) and male powerlifters (12) reported enhanced isotonic muscle strength as assessed by 1RM bench press (12, 18) or lifting volume at 4–6RM (13). A single study has been reported with women consuming creatine along with resistance training (24). The initially untrained women who consumed creatine had 20–25% greater increases in their 1RM for 3 of the 7 exercises tested after 10 weeks of resistance training. No studies have been reported regarding the benefits of oral creatine during resistance training in women athletes.

Another potential benefit of creatine is that increased reliance on phosphocreatine (PC) may reduce ATP generation via glycolysis and thus accumulation of blood lactate. Several studies report a lower lactate accumulation after resistance exercise when subjects were supplemented with creatine. Greenhaff et al. (6) found no difference in blood lactate accumulation after subjects completed repeated bouts of isokinetic knee extension before, compared with after, creatine supplementation. However, since the subjects did more

work during this test after creatine supplementation, this was interpreted as evidence of reduced reliance on anaerobic glycolysis.

Few published studies have examined the effect of chronic creatine during resistance training. In addition, most studies have used short-term supplementation in men, even though many women use the supplement and most individuals take it for prolonged periods. Thus, the purpose of this study was to look at the effects of chronic creatine supplementation on muscle performance and body composition of women athletes involved in resistance training. The study was designed to determine whether creatine supplementation enhanced training adaptations produced by resistance training.

Methods

Subjects and Design

Twenty NCAA Division 1 women lacrosse players between the ages of 18 and 22 volunteered to participate in the study, which was approved by the Institutional Board for Research Involving Human Subjects. This team was chosen because 1 of the coauthors was an assistant coach for the team; the daily contact she had with the women involved in the study was expected to improve compliance with study requirements. In addition, these women were each expected to participate in a similar resistance-training program during the preseason period designed by the university strength coach. Thus, the women had a similar resistance-training prescription (based on their own muscle strength) and performance goals. Each subject completed a survey concerning dietary habits, body weight history, and general health. None of the subjects reported using creatine supplements during the previous 2 months. All testing was performed during the fall preseason training program for lacrosse.

The subjects were randomly divided in a double-blind fashion into creatine (C) and placebo (P) groups. The C group received 4×5 g $\cdot$ d^{-1} of creatine monohydrate in capsules (donated by SportPharma, Inc., Concord, CA) or capsules of identical appearance containing sucrose for 7 days (days 4–10); each group received 2 g $\cdot$ d^{-1} of their supplement for the remainder of the study (days 11–35). The subjects were instructed to ingest the supplements with plenty of water at least 3 hours apart during the first week and in the morning for the rest of the study. A blank calendar was given to all subjects to record the time of day that they consumed the supplement. One of the investigators (MB) was in daily contact with the team during practice and regularly reminded them to consume their supplements.

Throughout the supplementation period, the subjects did a regular resistance-training program, which consisted of a free-weight bench press and Nautilus leg extension cycle based on each subject's 1RM. All workouts were supervised. Week 1 consisted of 4 sets of 10 repetitions at 40–60% of 1RM. Subjects rested for 3–5 minutes between sets. Intensity and number of sets progressed over the 5 weeks, such that 5 sets were performed at 50, 75, 80, and 85% of 1RM (10 repetitions for the first set and 5 for the other sets). Other free-weight exercises included bicep curls (3 sets of 8), tricep pushdowns (3 sets of 8), lat pulldowns (3 sets of 8), wrist curls (2 sets of 10), jump shrugs (3 sets of 10), and medicine ball throws (2 sets of 10) using the maximum loads they were able to perform without sacrificing technique. The exercise training was the same for all subjects and was done on Monday, Wednesday, and Friday of each week. A minimum of 85% attendance was required at the strength-training session (confirmed via a sign-up sheet) for inclusion in the study. Two subjects were dismissed from the study because of illness. Another subject became injured (compartment syndrome). One subject dropped out for personal reasons (she quit the team). Therefore, the final number of subjects in each group was 7 in C and 9 in P.

Measurements

Body weight was assessed after an overnight fast to the nearest 0.1 kg on days 1, 2, and 38. Body density was determined on days 1 and 38 using hydrodensitometry with a chair suspended by a load cell that was interfaced with a computer. The three highest underwater weights from 8 measurements and residual volume were averaged (26). Body density was also estimated with skinfold measurement using the equation of Jackson et al. (11). Siri's equation (21) was used to convert density to percentage body fat.

On days 3 and 39, 1RM of the bench press (free weights) and leg extension (Nautilus) was tested. The subjects warmed up by performing 2 sets of 5 repetitions at 50% of their estimated 1RM; an average of 3 trials with 3 minutes rest between was needed to reach 1RM for all subjects. Criteria for a full repetition on the leg extension included proper technique and a body angle such that the upper leg was 90° from the floor. Criteria for a full repetition on the bench press included proper technique (hips never lifted off the flat bench) and full arm extension.

Muscle endurance was assessed using the test described by Greenhaff et al. (6). It involved 5 sets of 30 repetitions of a unilateral isokinetic knee extension (Biodex Corporation, Shirley, NY) at 180 deg $\cdot$ s^{-1} separated by a 1 minute rest between sets. A practice test was done on day 1 to familiarize the subjects with the test. Subsequent tests were performed on day 2, prior to initiation of the supplements, and on day 38. Warm-up prior to the test included walking in place and stretching for several minutes. The subjects' dominant legs were attached to the measurement arm of the

Table 1. Subject characteristics.

Group	Age (yr)	Height (cm)	Weight (kg)
Creatine	18.1 ± 1.7	163.9 ± 0.8	60.6 ± 2.6
Control	19.5 ± 1.9	166.2 ± 0.7	61.1 ± 2.3

Values are means with standard errors.

Biodex machine, and they received consistent verbal encouragement to perform maximally during the repetitions. Total work performed, as well as an index of muscle fatigue, were calculated from this test. Work fatigue within the first and last set was calculated by subtracting the work output of the last 10 repetitions from the work output in the first 10 repetitions, divided by the work output in the first 10 repetitions. Fatigue for the performance test was calculated by determining the work fatigue during the fifth set as a percentage of work fatigue during the first set. Total work was the sum of the work done during each of the 5 sets.

Blood lactate was obtained from finger prick blood samples at rest and 3 minutes after the endurance test. Blood was collected into capillary tubes in duplicate and run in duplicate using a YSI Model 1500 Sidekick analyzer (Yellow Springs Instrument, Yellow Springs, OH). Blood lactate accumulation was calculated as the difference between the postaverage lactate and the preaverage lactate. Resting, fasted serum glutamyltransferase (GGT) (colorimetric, #545, Sigma Chemical Co., St. Louis, MO) and urea nitrogen (BUN) (colorimetric, #66, Sigma) were analyzed from venous blood samples taken on day 3 (just prior to supplementation period), day 19 (approximately half-way through supplementation period), and day 39 (end of supplementation). Both assays were run in triplicate.

Statistical Analysis

A 2-way ANOVA with repeated measures was used to determine differences between the groups for the performance, anthropometric, blood lactate accumulation, blood GGT, and BUN. Throughout the data analysis, differences with an alpha level less than or equal to 0.05 were considered significant.

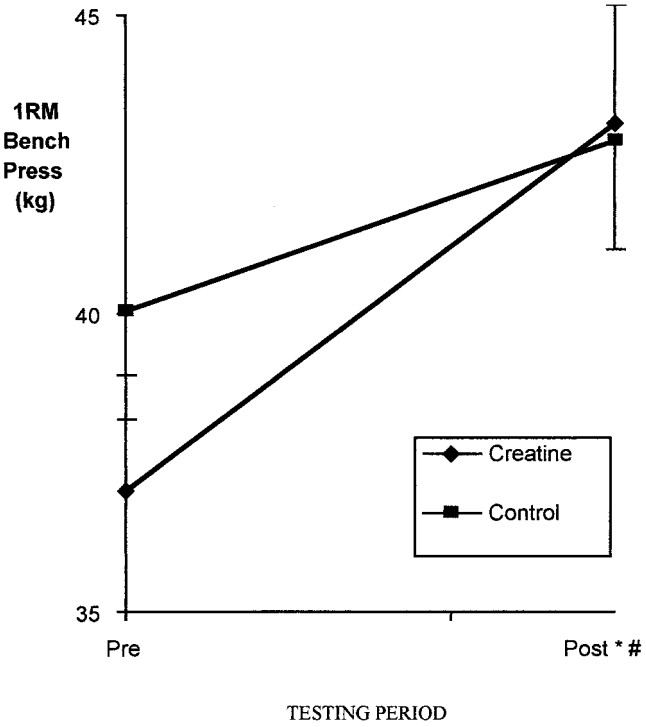

Figure 1. Bench press 1 repetition maximum (1RM) before and after creatine supplementation. Values are averages with standard error of the mean. * = significant effect of time; # = significant interaction between group and time.

Results

There were no initial differences between groups for age, height, weight, body fat, or fat-free mass (Table 1). Self-reported information from the diet-health questionnaire revealed that 56% of women considered themselves vegetarian (3/7 in C and 6/9 in P), while 24% consumed red meat, poultry, and/or fish less than twice a month. At the time of the study, no subjects were attempting to lose weight; the average weight fluctuation over the past 12 months was 0.35 ± 0.9 kg.

Table 2. Mean total work (TW) and fatigue (F) values for creatine and control groups before and after the experimental period.

Group	*n*	F* Pre (%)	F Post (%)	TW Pre (ftlbs)	TW Post# (ftlbs)
Creatine	7	149 ± 3.08	145 ± 3.37	5,964.87 ± 401.15	6,366.09 ± 401.15
Control	9	146 ± 3.15	157 ± 3.23	6,231.38 ± 353.78	6,397.40 ± 352.78

Values are means with standard errors.
* Fatigue = work fatigue of bout 5 as a percent of work fatigue of bout 1.
# = significant time effect across groups (p = 0.037).

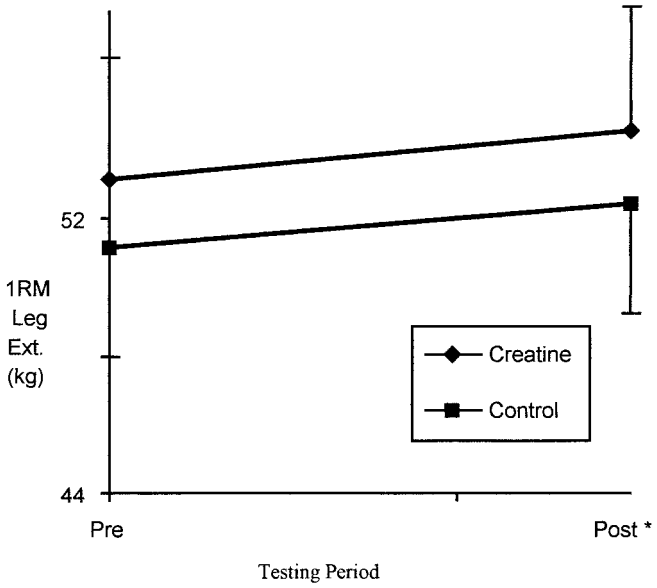

Figure 2. Leg extension 1RM before and after creatine supplementation. Values are averages with standard error of the mean. * = significant effect of time.

There were no differences between groups for initial 1RM of the bench press or leg extension. Bench press strength increased an average of 4.5 kg for both groups over time (Figure 1). Eighty-seven percent of the women increased their bench press 1RM (range 2.3–9.1 kg). There was a significantly greater increase in bench press strength for C (6.2 kg, 16.7%) compared to P (2.8 kg, 7.1%). Leg extension 1RM increased by an average of 1.4 kg (3.3%); this was significant for the groups combined, but was not different by group (Figure 2).

No differences were observed between groups for initial total work or work fatigue during the muscular performance test (Table 2). There was not an effect of the training program or the supplement on work fatigue. There was a significant mean increase of 3.6% for total work done across the 5 sets for groups combined with no effect of the supplement on total work.

Although there was a significant increase in body weight for both groups (0.5 kg), there was no influence of supplement on this change. There was a significant time effect and a significant interaction of groups over time for percent body fat by skinfold technique: 85.7% of subjects in the creatine group decreased their body fat, while only 33.3% of subjects in P reduced their body fat. (Table 3) The mean decrease for percent body fat by skinfold for C was 1.2%, while P slightly increased their average body fat by a mean of 0.3%. Although there was no significant effect of creatine supplement on fat-free mass by skinfold noted, there was a significant increase in fat-free mass when groups were combined.

There was no effect of the supplement on body fat or fat-free mass by hydrostatic weighing; however, there was a trend for percent body fat by hydrostatic weighing to decrease over time ($p = 0.11$); fat-free mass measured with this method was not altered by the training program (Table 3).

There were no initial differences between the groups for serum BUN or GGT. No effect of time or supplement was seen for GGT (Table 4). Although there were no significant differences across groups and no interaction over time for BUN (Table 4), there was a trend ($p = 0.06$) for increased BUN at the end of the study compared to pre- or midtraining values (Table 4).

There were no initial differences between groups for blood lactate accumulation over the first performance test, but there was a trend ($p = 0.07$) for the P group to have less accumulation of lactate when both

Table 3. Mean values for body composition before and after experimental period.

		%Body fat		Fat-free mass (kg)	
	n	Pre	Post[1,2]	Pre	Post[1]
Skinfold technique					
Creatine	7	22.5 ± 0.92	21.3 ± 0.92	46.99 ± 1.92	48.09 ± 1.92
Control	9	22.5 ± 0.18	22.6 ± 0.18	47.23 ± 1.69	47.49 ± 1.69
		%Body fat		Fat-free mass (kg)	
	n	Pre	Post[3]	Pre	Post
Hydrostatic weighing					
Creatine	7	23.0 ± 1.03	22.4 ± 1.03	46.34 ± 1.24	46.96 ± 1.24
Control	9	23.2 ± 0.91	23.1 ± 0.91	47.12 ± 1.12	47.38 ± 1.12

Values are means with standard error.
[1] Significant time effect.
[2] Significant interaction between groups over time.
[3] Trend for time effect ($p = 0.112$).

Table 4. Mean GGT and BUN values for creatine and control groups before and after experimental period.

	n	Pre (mmol/L)	Mid (mmol/L)	Post (mmol/L)
GGT				
Creatine	7	18.81 ± 1.95	17.92 ± 1.95	18.59 ± 1.95
Control	9	21.29 ± 1.72	21.04 ± 1.72	21.80 ± 1.72
BUN*				
Creatine	7	1.25 ± 0.03	1.22 ± 0.03	1.30 ± 0.03
Control	9	1.20 ± 0.03	1.23 ± 0.03	1.29 ± 0.03

Values are means with standard error.
* Time effect trend, $p = 0.06$.

trials were combined (Table 5). There were no changes in blood lactate accumulation over time.

Discussion

The major findings of this experiment are that a group of women athletes increased their bench press strength and decreased their percent body fat as measured by skinfold technique more over 5 weeks of a regimen of oral creatine supplementation than those consuming a placebo. However, results were mixed in that neither body fat estimated using the hydrostatic weighing technique, nor muscle strength with the leg extension test, showed an effect of creatine.

Short-term creatine supplementation for 6–7 days has been shown to improve indices of muscle strength and power. Maximal isometric force and endurance during repeated contractions (14), as well as enhanced peak power of a jump squat test and number of repetitions of bench press at 10RM (25), were observed with short-term supplementation.

Other studies have focused on the ability of chronic creatine supplementation to augment strength gains in men athletes during their training program, including football players (13, 18), power lifters (12), and resistance-trained men (5) consuming daily creatine for periods for 26–56 days. Effects of creatine have been mixed depending on the muscle groups tested within these studies. The one consistent exercise, often the only test used, among these studies was the bench press; all of the studies reported enhanced performance of this exercise. Two of the 4 studies tested 1RM for this exercise, but the other 2 used 3RM (12) or the maximum number of lifts that could be done at a weight estimated by the coach to be 4–6RM for the athlete (13). Kreider et al. (13) found an increase in lifting volume for the bench press, but not for squat and power clean exercises. It is interesting that this is consistent with our finding of the enhancement of strength gain in the upper body, but not of exercises with more dependence on lower-body muscles.

One study examining the effect of creatine on strength gains in women has been published (24). This study had untrained women begin and continue a resistance-training program for 10 weeks. Strength gains for those consuming creatine, as assessed with 1RM tests, were greater for the leg press, leg extension, and squat; a trend for improvement was seen for the bench press and leg curl, with no effect on shoulder press strength improvement. Since these women were initially untrained, the strength gains were substantial, even for the placebo group. For example, leg extension 1RM increased by about 57% for the placebo group in this study. Strength gains for the trained women in our study were much more modest. As a comparison, leg extension 1RM increased only 3.3% for our subjects. Upper-body strength as assessed using bench press 1RM improved two- and fivefold more for P and C groups, respectively, than the lower-body test in our study. Thus, the fact that our subjects may have been closer to their maximal strength potential for leg extension may have limited any effect of creatine for this muscle group, while more opportunity to influence upper-body strength existed. The shorter period of resistance training, half that of Vandenberghe et al. (24), may also contribute to the lower strength gain observed in our study. Although we cannot validate that muscle creatine or creatine phosphate concentrations were increased in these women, the loading and maintenance oral creatine regimen was similar to other work that identified an increase in these muscle metabolites (10).

Possible mechanisms for the increase in strength gains with creatine include an increased stimulus for muscle growth because of the improved quality of the workouts. For example, an enhanced ability to resynthesize PC between sets of exercise may have increased the total work done during the sessions by allowing more repetitions to be completed.

The lack of effect of creatine on total work done or fatigue over 5 sets of isokinetic contraction are in conflict with those of Greenhaff et al. (6), who used the same protocol. They reported that muscle peak torque during most of the 5 sets of the knee extension was enhanced following creatine supplementation. The

Table 5. Blood lactate means and accumulation for creatine and control groups before and after experimental period.

	n	BLA Pre (mmol/L)	BLA Post* (mmol/L)
Creatine	7	4.90 ± 0.48	4.33 ± 0.48
Control	9	3.69 ± 0.42	3.82 ± 0.42

Values are means with standard errors.
* Group effect trend ($p = 0.067$).

subjects in the Greenhaff et al. (6) study were not highly trained and thus may have significantly improved as a result of greater increases in the levels of muscle PCr and Cr seen in untrained subjects. Similarly, Vandenberg et al. (24) found enhancement of torque production during the 5 sets of 30 isokinetic arm flexions in women who consumed creatine concurrent with resistance training. Both of these studies used relatively untrained subjects. The trained athletes studied by Kreider et al. (13) did not improve their total work accomplished during 12 6-second sprints on a cycle ergometer. Trained athletes have been reported to have near-maximal levels of muscle creatine, and thus may have less potential for improvement in performance than untrained subjects using this supplement (17).

Several studies have noted changes in body weight of the subjects, from 1.7 to 2.9 kg in male resistance trainers, subsequent to creatine supplementation over a period of 1–4 weeks (5, 12, 13, 18). The composition of the weight gain is hypothesized to be related to an increase in total body water or muscle protein; however, few studies have examined this. It is interesting that the study that used resistance training in untrained subjects (24), as well as our own, showed a similar increase in body weight of women during resistance training regardless of consuming creatine or a placebo. However, in contrast to the similar increase in fat-free mass (skinfold) noted for both groups in our study, the women studied by Vandenberg et al. (24) who consumed creatine had a greater increase in lean tissue than those given a placebo. Finally, creatine did not have a fat loss–enhancing effect for the women studied by Vandenberg et al. (24). Our results were mixed, in that proportion of body fat measured using skinfold technique fell more for the women taking creatine, but the hydrostatic method described a similar drop in body fat for both groups. The reason for a difference in the statistical effect of creatine on body fat depending on technique used is not clear. However, it is important to note that the numerical trend was the same for both techniques (i.e., no change in P, decrease for C), but the variability in the measurement was greater for the hydrostatic weighing procedure. Thus, statistical power was lower for this analysis. It is also possible that change in body water status could have influenced hydrostatic weighing data in the C group. In other words, if creatine increased body hydration, this would result in an underestimation of body density and an overestimation of body fat after supplementation using hydrodensitometry. Most researchers studying resistance-training men did not find more fat loss in those consuming daily creatine (5, 12, 13), and 1 study actually reported fat loss only in the placebo group (18). Thus, the effect of creatine supplementation on body composition is inconsistent.

Our finding that lactate accumulation did not change in spite of higher total work accomplished during the posttest for both groups suggests a training effect that increases reliance on aerobic ATP production during this test. However, creatine supplementation did not influence lactate concentration after the repeated contractions. Greenhaff et al. (6) interpreted a beneficial effect of creatine in that the supplemented group did more work during the repeated leg extension performance test but had the same postexercise lactate as they did prior to supplementation. Other research concerning the effect of creatine on lactate accumulation following repeated sprints is mixed with some studies that reported lower lactate (1, 20), and others finding no effect (2, 16).

Our study did not find evidence of negative health effects of creatine. Although 1 subject in the creatine group developed compartment syndrome, her symptoms began prior to the supplementation period. The increase in BUN was observed for both groups, and may have reflected overall protein catabolism consequent to the training, or relative dehydration on both groups as a result of training. Creatine did not affect this change. Kreider et al. (13) noted an increase in BUN only for the group consuming a supplement containing taurine, disodium phosphate, and potassium phosphate, but not for the group consuming that supplement with added creatine. Their study found, however, that some liver enzymes were slightly elevated in subjects consuming creatine. Interestingly, the enzymes LDH and AST showed this elevation, while the enzyme we measured, GGT, did not increase. This suggests that measurement of 1 liver enzyme may not be fully indicative of effects of creatine on liver function. Future studies should measure multiple liver enzymes during long-term creatine supplementation to determine normal organ function.

Practical Applications

This study suggests that oral creatine supplementation increases strength improvements for the upper body in female athletes doing resistance training. Creatine did not influence body weight or lean body mass gain that occurred because of the resistance training program. The effect of this supplement on body fat is unclear since measurement by 1 technique showed enhanced fat loss with creatine, while the other showed no effect. Finally, we found no indication of liver or kidney malfunction, as measured by blood metabolites, with daily creatine supplementation in women over 5 weeks.

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