Creatine as an Ergogenic Aid for Female Athletes

Joan M. Eckerson, PhD, FNSCA
Department of Exercise Science and Pre-Health Professions, Creighton University, Omaha, Nebraska

ABSTRACT

CREATINE (CR) IS AN EFFECTIVE ERGOGENIC AID FOR FEMALE ATHLETES, BUT MAY BE OVERLOOKED BECAUSE OF A PERCEPTION THAT IT CAUSES WEIGHT GAIN. STUDIES USING WOMEN SHOW THAT BOTH SHORT-TERM AND LONG-TERM CR SUPPLEMENTATION ENHANCES MUSCULAR STRENGTH AND POWER AND OTHER MEASURES OF ANAEROBIC AND AEROBIC EXERCISE PERFORMANCE WITH MINIMAL EFFECTS ON BODY COMPOSITION. THEREFORE, FEMALE ATHLETES INVOLVED IN SPORTS THAT REQUIRE A LOW BODY WEIGHT, AESTHETICALLY JUDGED SPORTS, AND WEIGHT-CLASS SPORTS MAY FIND CR TO BE A USEFUL DIETARY SUPPLEMENT. THE CURRENT REVIEW SUMMARIZES RESEARCH FINDINGS THAT USED WOMEN AS SUBJECTS AND PROVIDES GUIDELINES FOR SUPPLEMENTATION.

Adequate dietary and caloric intake, hydration, and nutrient timing are paramount for optimal athletic performance and recovery. However, there are a number of dietary supplements that have been shown to improve performance beyond training alone, including creatine (CR) and whey protein, but they seem to be underused by female athletes. Survey research examining the reasons why athletes use dietary supplements indicates that there may be a disconnect between the reasons female athletes say they take dietary supplements and what they actually do in practice (14,20,23). For example, in a survey of 88 female National Collegiate Athletic Association (NCAA) Division I athletes by Froiland et al. (14), the primary reasons women indicated that they took dietary supplements were to increase strength and power, gain muscle, improve speed and agility, increase energy, and enhance their health. However, only 3.4% reported taking CR, 2.5% reported consuming protein powders, and <1% reported taking whey protein or a weight gainer. In actual practice, the women used multivitamins, energy and fluid replacement drinks, and calorie replacement products. In 2 related studies, Kristiansen et al. (23) and Jacobson et al. (20) also found that energy replacement products in the form of carbohydrate bars, shakes, or sports drinks were most popular with women, whereas men were more likely to use CR, HMB (beta-hydroxy-beta-methylbutyrate), whey protein, amino acids, and weight gainers. In the study by Kristiansen et al. (23), 42.7% of the female varsity level athletes (n = 89) did report using either protein powder or protein bars, but none of them used CR. Interestingly, one-third of both male and female athletes surveyed in the study by Froiland et al. (14) did not consider calorie replacement and fluid replacement products as dietary supplements, which indicates that there remains a need to better educate athletes about the difference between dietary supplements and food.

There are a number of studies that show that CR supplementation is an effective ergogenic aid for increasing strength, power, and overall athletic performance in female athletes involved in a wide variety of sports, but it seems to be largely underused by this population. Therefore, the purpose of the current review is to provide a general overview of CR and to summarize research findings of studies that used women as subjects to help dispel possible misconceptions and provide guidelines for supplementation.

OVERVIEW OF CREATINE AND POTENTIAL MECHANISMS OF ACTION

Although there may be a large amount of variability in the response to CR by individual athletes, it has been shown to be a safe and effective ergogenic aid that does not usually result in significant increases in body weight (BW) or fat-free mass (FFM) in women. Thus, an unwillingness among some female athletes to supplement with CR because of a fear of weight gain or other adverse side effects may be largely unfounded. Furthermore, many reported adverse effects (bloating, cramping, and diarrhea) do not tend to be substantiated in controlled research studies and are likely due to improper mixing and/or dosing.

A common misconception among the general population, and perhaps by many female athletes, is that CR is an anabolic steroid. In truth, CR is a non-essential protein compound

KEY WORDS: women; dietary supplement; nutrition; training; strength; exercise performance
synthesized in the liver, pancreas, and kidneys from 3 amino acids (arginine, glycine, and methionine), and is also consumed in the diet from meat, fish, and other animal products. For example, beef, tuna, salmon, and pork all contain approximately 4-5 g of CR per kilogram (~2.2 lb). However, the average intake for individuals who are eating meat as part of a mixed diet is only about 1 g·d⁻¹ (47). The average CR pool for a 70 kg individual ranges from 120 to 140 g and approximately 2 g·d⁻¹ is lost each day in the urine in the form of creatinine (2). This loss is replaced by both dietary consumption and endogenous CR synthesis, which is also about 1 g·d⁻¹. Given that daily intake and excretion are approximately the same, the most efficient way to increase CR stores in the body is through dietary supplementation.

In the body, CR is primarily stored in skeletal muscle as either free CR (~40%) or as phosphocreatine (PCR; ~60%), which plays a critical role in the phosphagen energy system. Therefore, CR supplementation is most effective for high-intensity, short-duration activities or repeated bouts of high-intensity exercise with short rest periods such as jumping, sprinting, and strength training, because increased levels of PCR can more rapidly rephosphorylate adenosine diphosphate to adenosine triphosphate (ATP) through the CR kinase reaction and, thereby, delay the onset of fatigue. In addition, PCR acts to buffer H+ ions that accumulate from lactic acid during high-intensity exercise; which also helps prevent fatigue. In practice, this essentially means that an increase in intramuscular total muscle Cr (TCR) stores should allow for an increase in training intensity, faster recovery and, thus, a greater stimulus for training. Over time, a higher training stimulus results in greater physiological adaptations (i.e., hormonal adaptations, increased cell hydration, and gene expression) that lead to increases in muscle mass, strength, and muscle fiber hypertrophy (47). For example, Burke et al. (4) reported that CR supplementation during high-intensity resistance training resulted in a greater increase in insulin-like-growth-factor-I (IGF-I) compared with training alone in healthy men and women. IGF-I is an anabolic hormone that stimulates several genes that result in muscle hypertrophy, and has also been shown to increase satellite cell activities, which are the cells responsible for skeletal muscle hypertrophy in humans (4).

**CREATINE DOSING STRATEGY**

The typical dosing strategy consists of a 4- to 7-day loading phase in which 20 g·d⁻¹ is ingested in 4 equal doses (5 g) approximately every 4 hours followed by a maintenance dose of 3-5 g·d⁻¹ to maintain elevated CR levels. To account for differences in BW between athletes, another recommended dosing strategy is to consume 0.3 g·kg⁻¹·d⁻¹ during the loading phase and 0.03 g·kg⁻¹·d⁻¹ during the maintenance phase (47). Although it is typically recommended that an individual CR load for 4-7 days, it has been reported that CR uptake into muscle is greatest during the first 2 days of loading (18). It has also been shown that a dose of 3 g·kg⁻¹·d⁻¹ for 28 days is as effective as CR loading for increasing TCR stores (19). Therefore, “slowly loading” the muscle may increase performance and reduce side effects that are occasionally reported during a 4- to 7-day loading regimen.

Several studies that have examined the effect of CR loading on TCR and/or PCR content have found that women respond similarly to men after loading (18,25,31,35,45), with most studies reporting an increase in muscle TCR stores between 18 and 20% (18,19,25) and increases in PCR ranging between 6.0 and 17.8% (19,25,35,45). McKenna et al. (25) examined the effect of CR loading using 8 men and 6 women and reported that the muscle TCR content before loading was not significantly different between sexes, and that there were no differences in the magnitude of change in TCR content after 5 days of CR loading (21.5 and 19.0% for men and women, respectively). Similarly, Harris et al. (18) reported a 17.2% increase in muscle TCR in a pooled sample of men and women and found that there were no apparent effects of age or sex on muscle TCR content after supplementation.

Although increases in TCR content after supplementation are similar between men and women, it is important to note that about 20-30% of individuals are nonresponders (16). In a study that compared responders and nonresponders to CR loading, Syrotuik and Bell (41) reported that responders had lower baseline levels of intramuscular free CR and PCR, a higher percentage and greater cross-sectional area of fast twitch muscle fibers, and more FFM before loading when compared with nonresponders. In their study (41), the loading dose was 0.3 g·kg⁻¹·d⁻¹ for 5 days and they used 11 college-age men as subjects. Although these findings may not be directly applied to women, studies that have compared the muscle make-up between sexes (28,39) indicate that the distribution of slow-twitch and fast-twitch fiber types is similar between men and women, and that differences in strength are primarily due to the greater cross-sectional area of both fibers in men. Therefore, it seems reasonable to propose that women with the same physiological characteristics as the responders in the study by Syrotuik and Bell (41) may be the best candidates for CR supplementation. However, future studies are necessary to replicate their findings using women as subjects.

Female athletes who consume a vegetarian diet may also respond well to CR supplementation, because it has been shown that vegetarians have lower initial levels of stored CR in the muscle and, therefore, have an increased capacity to load CR (4,5,46,48). In addition, there does not seem to be any difference in the gene expression of the transporter protein responsible for transferring CR into the muscle between meat-eaters and vegetarians, or its potential effects on performance (5,34,48). Shamrot
et al. (34) found that male vegetarians demonstrated similar increases in mean power output and peak power output compared with meat-eaters during short-term, maximal exercise on a cycle ergometer after 6 days of CR loading (21 g·d⁻¹), and Burke et al. (5) found that male and female vegetarians experienced greater increases in muscle TCR, FFM, and total work during isokinetic leg extension/flexion compared with meat-eaters after a 7-day loading and 49-day maintenance phase during 8 weeks of resistance training. Therefore, CR supplementation seems to have ergogenic effects for both vegetarians and meat-eaters.

**EFFECT OF CREATINE SUPPLEMENTATION ON STRENGTH PERFORMANCE AND BODY COMPOSITION**

Although studies using recreational and highly trained female athletes as subjects are lacking, both long-term and short-term CR supplementation have been shown to enhance muscular strength and power with minimal effects on body composition. Vandenberghe et al. (45) were among the first to conduct a comprehensive study to determine the effect of long-term CR supplementation during both a 10-week training and detraining period in 19 healthy, untrained women (age range = 19–22 years). The subjects were matched for arm flexor strength and BW and were randomly assigned to ingest 5 g CR 4 times daily (20 g·d⁻¹) for 4 days as a loading dose, followed by a maintenance dose of 5 g·d⁻¹ during 10 weeks of resistance training (1 hour; 3 × week) or a maltodextrin placebo (PL) in an identical dosing pattern.

Performance measures included 1 repetition maximum (1RM) testing for upper (shoulder press, bench press) and lower-body exercises (leg press, squat, leg extension, leg curl), and 5 bouts of 30 maximal contractions of the right arm flexors separated by 2 minutes rest on an isokinetic dynamometer to determine average torque output. Body composition (through underwater weighing [UWW]) was also determined before the loading phase, and at 5 and 10 weeks of the resistance training program.

After 10 weeks of training, a subsample of subjects in each group continued to supplement for an additional 10 weeks, but did not train, followed by a 4-week period in which subjects stopped taking their supplements and continued to detrain. The results showed that there were no significant differences in arm flexor torque between groups after loading, however, the CR group demonstrated significantly greater torque values at all other time points until the end of the study when supplementation had stopped for 4 weeks. In addition, increases in TCR for leg press, leg extension, and squat were 20–25% greater (p < 0.05) in the CR group after the 10-week training program compared with PL. The findings for body composition showed that there were no significant differences between groups for BW and percent fat (% fat); however, the change in FFM was greater (p < 0.05) in the CR group after both 5 weeks (2.0 kg) and 10 weeks (2.6 kg) of training compared with PL (1.1 and 1.6 kg, respectively).

These findings (45) showed that long-term CR supplementation was effective for increasing lower-body strength and FFM beyond training alone in untrained women and helped maintain strength during a period of detraining. The finding that CR supplementation increased strength performance without significantly affecting BW or % fat has also been reported by several others (3,12,21,27,33,40), and suggests that women may benefit from CR without experiencing undesirable changes in BW.

In another study that used trained women as subjects, Brenner et al. (3) examined the effect of 5 weeks of CR supplementation on strength and body composition in 16 NCAA Division I female lacrosse players during their preseason strength and conditioning program. The CR group received a loading dose of 20 g·d⁻¹ (4 × 5 g·d⁻¹) in capsule form for 7 days, followed by a maintenance dose of 2 g·d⁻¹ for 4 weeks. The PL group followed the same protocol and ingested sucrose capsules. Body composition (through UWW) and 1RM testing for the bench press and leg extension were measured presupplementation and postsupplementation. The results showed that the CR group had a significantly greater increase in 1RM bench press (6.2 ± 2.0 kg) compared with PL (2.8 ± 1.8 kg); however, there were no significant differences between groups for FFM or % fat.

Larson-Meyer et al. (24) also examined the effects of CR supplementation (5-day loading dose of 15 g·d⁻¹ followed by a 12-week maintenance dose of 5 g·d⁻¹) during 13 weeks of resistance training on strength and body composition in female collegiate soccer players (n = 14). The results showed that CR led to significant increases in 1 RM strength for the bench press (18%) and squat (24%) compared with PL (9 and 12% increases for bench and squat, respectively). Both groups experienced similar increases in BW (CR = 2.5 kg; PL = 3.6 kg) and FFM (CR = 1.6 kg; PL = 1.1 kg), with no significant differences between groups.

Short-term CR supplementation has also been shown to significantly increase muscular power in women. In a study by Kambis and Pizzedda (21), 22 college-aged women randomly received a 5-day CR loading dose relative to FFM (0.5 g·kg⁻¹·FFM divided into 4 equal doses) or a PL and were tested for isokinetic strength of the preferred quadriceps group, thigh circumference, and BW. Time to peak torque for leg extension decreased (p < 0.05), and average power for leg extension and flexion significantly increased in the CR group compared with PL. However, there were no differences for changes in BW, FFM, % fat, mid-quadriceps circumference, or skinfold thickness of the measured thigh between groups.

It is important to note that not all studies report a positive effect of CR on strength performance. For example, Ferguson and Syrotuik (13) found that CR supplementation had no additional
benefits compared with training alone in 26 women (18–35 years) who had been strength training 2–3 d wk⁻¹ for 1 year before enrollment. In this study (15), the CR loading dose was 0.3 g·kg⁻¹·d⁻¹ for 7 days followed by a maintenance dose of 0.03 g·kg⁻¹·d⁻¹ for 9 weeks. All subjects were tested at baseline, 5, and 10 weeks for IRM bench press and incline leg press, and completed 5 sets of multiple repetitions to exhaustion at 70% IRM. The results showed that both the PL and CR groups experienced similar increases in strength and FFM over time, without a significant change in BW over the 10-week study. The authors (13) suggested that the lack of nonsignificant findings may have been due to nonresponders in the CR group, an insufficient loading dose, insufficient training volume, or a combination of these factors.

**EFFECT OF CREATINE ON ANAEROBIC INDICES OF PERFORMANCE AND FATIGUE**

Several investigations using women as subjects have studied the effects of CR supplementation on fatigue and other anaerobic indices of performance with most of the studies showing favorable results. For example, CR loading has been shown to improve anaerobic working capacity (AWC) estimated from the critical power test. AWC represents the maximal work potential associated with the phosphagen energy system (ATP + PCR) and, therefore, provides an estimate of anaerobic power. Using a double-blind, crossover design, Eckerson et al. (12) examined the effect of 2 and 5 days of CR loading (20 g·d⁻¹) on AWC in 10 physically active women (mean age ± SD = 22 ± 5 years) and found that 5 days of supplementation resulted in a 22% increase in AWC (p < 0.05), whereas the PL trial resulted in a 5% decline. In a follow-up study (Eckerson et al. (12)) to determine whether phosphate salts added to CR had an added effect on AWC, it was found that AWC was increased by 13.0 and 10.8% after 6 days of loading with CR or CR + phosphate salts, respectively, compared with a 11% decline in the PL group. These findings were consistent with other studies using physically active women as subjects that reported increases in AWC ranging from 10 to 15% after CR loading (10,37). Although muscle TCR concentrations were not directly measured in the studies described above, it is likely that the observed increases in AWC were due to an increase in muscle PCR content.

It has also been suggested that an increase in PCR levels after CR loading delays the onset of neuromuscular fatigue (NMF), which is characterized by an increase in the electrical activity of the working muscles over time and reflects the progressive recruitment of additional motor units and/or an increase in the firing frequency of motor units that have already been recruited (38,40). In 2 separate studies, Stout et al. (40) and Smith et al. (38) showed that 5 days of CR loading significantly delayed the onset of NMF during incremental cycling exercise compared with PL using both active and highly trained female athletes. Both authors suggested that the delay in NMF was due to an increase in intramuscular levels of PCR, which may have resulted in a greater capacity to delay anaerobic glycolysis and, in turn, decreased the accumulation of lactic acid and ammonia in the working muscles and the blood.

Tarnopolsky and MacLennan (43) showed that CR (5 g, 4 × d⁻¹ × 4 d) increased peak and relative peak anaerobic cycling performance (3.7%), maximal voluntary contraction of the dorsiflexors (6.6%) with no sex-specific responses using a sample of 24 recreationally active men and women, and suggested that both physically active men and women can improve performance during high-intensity exercise after short-term CR supplementation.

In agreement, Ziegenfuß et al. (50) reported that 3 days of CR supplementation (0.35 g·kg⁻¹·d⁻¹) increased sprint cycle performance in NCAA Division I athletes, and that the effect was greater in women as the sprints were repeated. Kirksey et al. (22) also reported that 6 weeks of CR supplementation (0.30 g·kg⁻¹·d⁻¹) improved vertical jump, power output, and work capacity on a cycle ergometer, and increased FFM in a combined sample of men and women collegiate track and field athletes (throwers, jumpers, and sprinters) compared with PL.

**CREATINE AND AEROBIC EXERCISE PERFORMANCE**

Although CR is typically recommended for athletes involved in sports that require repeated bouts of high-intensity exercise, the results of a few studies (1,30) suggest that an increase in CR and PCR stores may enhance submaximal oxygen uptake (V̇O₂) and recovery from aerobic exercise possibly by stimulating mitochondrial respiration and oxidative phosphorylation, and/or by acting as an H⁺ buffer to maintain pH. In a study by Aoki et al. (1) that examined the effect of 12 days of CR supplementation on resistance exercise performance (1RM and 3 sets to fatigue at 80% 1RM) after a 20-minute high-intensity run for distance, it was found that women who supplemented with CR completed more repetitions of leg press at 80% 1RM after the run compared with subjects taking a PL. Although there were no differences between groups for 1RM testing or the distance covered during the 20-minute run, there was a significant decrease in the number of repetitions to fatigue in the PL group versus CR group. Aoki et al. (1) suggested that an increase skeletal muscle PCR stores may have enhanced recovery after the run that allowed for improved performance during the resistance exercise.

Nelson et al. (30) showed that CR supplementation resulted in a lower V̇O₂ at submaximal workloads, and reduced the work performed by the cardiovascular system in a study that examined the effects of CR on cardiorespiratory responses during a graded exercise test (GXT). Subjects included trained men (n = 20) and women (n = 16) (age range = 21–27 years) who received either CR (20 g·d⁻¹ × 7 d) or a PL.
and completed a GXT using a cycle ergometer presupplementation and postsupplementation. CR supplementation increased (p < 0.05) total test time (20.3 ± 4 to 21.5 ± 3.5 minutes) compared with PL (17.3 ± 3 to 17.4 ± 3 minutes), and VO₂max and heart rate were also significantly lower at the end of first 5 stages of the GXT versus no change for PL. In addition, the ventilatory threshold increased significantly from pretesting to posttesting for the CR group (66–78% peak VO₂), with no change for the PL group (70–68% peak VO₂). It was suggested that the decreases in VO₂max and heart rate were due to increased stores of PCR in the muscle, which may have ultimately delayed mitochondrial respiration and lowered VO₂max (30).

Smith et al. (36) examined the effect of CR loading (20 g·d⁻¹ × 5 d) on aerobic power (VO₂max) and critical velocity (CV), which is a theoretical velocity that can be maintained for an extended period using only aerobic energy stores and, in this study, was estimated from 4 high-speed runs to exhaustion at 90, 100, 105, and 110% of peak velocity. The results showed that CR loading neither positively or negatively influenced VO₂max, CV, time to exhaustion, or BW, because there were no significant differences in any of these parameters between the CR or PL groups.

Many female athletes engaged in sports that require a low BW and also rely on aerobic metabolism, such as cross-country, long-distance running, and road cycling, may avoid using CR because they believe that it results in weight gain and would, consequently, impair performance. However, the results of the studies described above (13,30,36) suggest that CR supplementation may have some potential benefit for athletes in these types of sports without adverse effects on BW.

**CREATINE AND SPORTS PERFORMANCE**

The studies described above suggest that women with varying levels of training and fitness may experience improvements in both anaerobic and aerobic exercise performance from both short-term (3–7 days) and long-term CR supplementation (5–13 weeks) without major fluctuations in BW or FFM. Therefore, it seems reasonable that the improvements observed in the laboratory would carry over to competition and allow athletes who must compete in more than 1 event or game on the same day (i.e., softball double-header, tennis matches, swim competition, gymnastics, track and field events) or who must compete on successive days (i.e., basketball, soccer, and volleyball tournaments) to recover faster and, in turn, optimize performance and increase the odds of winning. However, given the difficulty of designing these types of studies, very few investigations have determined how CR supplementation may influence win-loss records and the execution of skills during competition.

Cox et al. (8) investigated the effects of short-term CR supplementation (4 × 5 g·d⁻¹ × 6 d) on performance during a field test that simulated soccer match play using elite female soccer players from the Australian National Team and found that the athletes in the CR group significantly improved repeated sprint performance and some agility tasks that mimicked soccer play compared with the PL group, but there was no effect on shooting accuracy. Therefore, how the improvements in sprint performance and agility would affect win-loss records over the course of a season remains to be seen.

Many studies have examined the effect of CR supplementation on swim performance, which is a sport that allows investigators to more closely mimic competition. Although most studies show that supplementation is ineffective for improving single-sprint swim performance (9,29,32,33,44), when swimmers were required to perform repeated sprints, there were improvements in the time to complete the series (17,32) and increases in work and power output (17).

**EFFECTS OF CREATINE SUPPLEMENTATION ON THE MENSTRUAL CYCLE**

To date, no studies seem to have directly examined the effect of CR uptake during different phases of the menstrual cycle, or whether CR intensifies premenstrual symptoms such as bloating, weight gain, and cramping. It has been recommended that when women are recruited as subjects for CR studies, they should be tested during their follicular phase to control for hormonal imbalances that may affect BW and other menstrual symptoms (42). However, this may not be realistic, because female athletes compete and train during all phases of their menstrual cycle; and at least 2 studies (15,49) indicate that the different phases of the menstrual cycle have no effect on high-intensity, anaerobic exercise performance. Therefore, in practice, it seems reasonable to suggest that female athletes could begin CR supplementation during any part of their cycle.

**FORMS OF CREATINE, TIMING, AND DOSING STRATEGIES FOR WOMEN**

Most research studies use CR monohydrate (CRM) in a powder or capsule form, but CR is also sold and marketed in a variety of ways, including bars, liquid CR, gels, gum, CR nitrate, and in an effervescent form as CR citrate. Because CRM in powder form is cost-effective and the most widely studied, that is what is typically recommended. Regardless of what form of CR is used for supplementation, it is imperative that it be purchased from reputable sources that sell products that have been made according to good manufacturing practice guidelines.

As previously discussed, a typical CR dosing strategy consists of a loading dose of 20 g·d⁻¹ administered in 4 equal doses (5 g) for 5–7 days followed by a maintenance dose of 3–5 g·d⁻¹, thereafter. Harris et al. (18) reported that CR uptake into muscle is greatest during the first 2 days of loading and, based on the findings of the studies described above; it seems that at least
2–3 days of loading may be needed to elicit an ergogenic effect. The range in the loading dose for the studies reviewed herein, whether expressed as an absolute value or relative to BW or FFM, ranged between \( 13 \text{ to } 24 \text{ g·kg}\text{−1} \). Therefore, a loading dose of 15–20 g consumed in 3–4 equal doses every 4–5 hours should meet the needs of a majority of female athletes, followed by a maintenance dose of 3–5 g·d\(^{-1}\) to maintain elevated CR levels in the muscle. Some research suggests that ingesting CR with simple carbohydrates, particularly during the loading phase, enhances uptake into the muscle because of the carbohydrate-mediated insulin release (47). Therefore, adding a serving of CRM to a carbohydrate replacement drink, a carbohydrate/protein recovery drink, or a glass of juice that contains \( 20 \text{ g of sugar} \) is recommended even if the athlete chooses to avoid the loading phase. Because exercise increases anabolic hormone release (7), it is recommended that CR be ingested immediately before or after exercise. However, it may be most convenient for athletes to consume CR in combination with carbohydrate and protein as part of their postexercise recovery drink to not only maximize CR uptake, but to also optimize glycogen repletion and protein synthesis. With regard to washout, there is no current evidence to suggest that cycling on and off CR is more effective than consuming a continuous maintenance dose, but because CR is most effective during training, if an athlete wishes to cycle off, it should be performed during periods of low training volume. In addition, there is some evidence to suggest that CR does not have to be taken everyday during the maintenance phase. For example, Candow et al. (6) found that 4–6 g of CR ingestion for just 2 or 3 days per week taken immediately before and after resistance training for 6 weeks (8–12 g dose total) had some beneficial effects on muscle size and strength. In addition, because the muscle becomes saturated with CR after a loading phase, Mesa (26) has suggested that a 3- to 5-g maintenance dose ingested 3 to 4 times per week may be enough to maintain muscle TCR stores. Based on the available research, Table 1 represents a dosing strategy recommended for female athletes.

It deserves mentioning that a common recommendation is to use \( 1.0 \text{ g·kg}\text{−1} \) BW of carbohydrate for mixing (47). However, considering an average BW of 63.5 kg (140 lb), this would translate to an extra 254 kcal per dose for a total of 1,016 kcals during a loading phase, which may not be well accepted by female athletes. Studies using as little as \( 18 \text{ g of dextrose (sugar)} \) in combination with CR (12,11) have been shown to elicit an ergogenic response; therefore, \( 20 \text{ g of simple carbohydrates} \) mixed with CR should be sufficient.

Finally, it is important for coaches and trainers to remind their female athletes that the most effective way to increase strength, power, and speed is through sport-specific resistance training and a diet adequate in calories, carbohydrate, and protein; and to stress to them that dietary supplements should never serve as a replacement for food.

### Table 1

**Recommended creatine supplementation dosing strategy**

<table>
<thead>
<tr>
<th>Dose/duration</th>
<th>Maintenance</th>
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<tbody>
<tr>
<td>No loading phase</td>
<td>3–5 g CRM per d for 5–6 wk; 3–5 g CRM; 3 to 4 × per wk postexercise</td>
</tr>
<tr>
<td>Loading phase</td>
<td>5 g CRM; 3 to 4 × per d (15–20 g·d(^{-1})) for 3 d; 3–5 g CRM; 3 to 4 × per wk postexercise</td>
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<tr>
<td>Ingest within 20–30 min postexercise with CHO (20–25 g) or CHO + PRO</td>
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<tr>
<td>If taken with CHO + protein, use a 2:1 or 3:1 ratio of CHO to PRO</td>
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<tr>
<td>Eat a meal within 2 h postexercise</td>
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**Example for a 140 lb (63.5 kg) female athlete using a 2:1 ratio:** ingest 0.4 g·kg\text{−1} CHO + 0.2 g·kg\text{−1} PRO + 5 g CR within 20–30 min postexercise, and 25 g CHO + 13 g PRO + 5 g CR

**CHO = carbohydrate; CRM = creatine monohydrate; CR = creatine; PRO = protein.**

### KEY POINTS

- CR is not an anabolic steroid—it is a protein-containing compound produced in the body that enhances performance by reducing fatigue, and enhancing recovery, which allows for a greater stimulus of training.
- CR increases strength and power in both trained and untrained women without large fluctuations in BW or muscle mass.
- CR may be especially beneficial for women involved in sports that require repeated short bursts of high-intensity exercise (i.e., basketball, volleyball, sprinters and throwers, soccer, field hockey, and tennis).

### SUMMARY AND PRACTICAL APPLICATIONS

In summary, a considerable number of studies (see Table 2) show that CR may serve as an effective ergogenic aid for female athletes involved in a wide variety of sports, but may be overlooked because they believe that CR will cause them to “bulk up” or result in unwanted weight gain. Because CR does not seem to result in increases in BW typically experienced by men, even female athletes involved in gravitational sports (cross-country, long-distance running), aesthetically judged sports (gymnastics, diving, figure skating), and weight-class sports (lightweight rowing, judo, combat sports) may find CR to be a useful dietary supplement that may not only enhance performance but also may serve to preserve FFM, because many of these types of athletes restrict energy intake.
### Summary of creatine studies on exercise performance and body composition in women

<table>
<thead>
<tr>
<th>Reference</th>
<th>Subjects</th>
<th>Dosage</th>
<th>Findings</th>
</tr>
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<tbody>
<tr>
<td><strong>Strength performance</strong></td>
<td></td>
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<tr>
<td>Brenner et al. (3)</td>
<td>Female collegiate lacrosse CR = 7; PL = 9</td>
<td>$4 \times 5 \text{g} \cdot \text{d}^{-1} \times 7 \text{d} \rightarrow 2 \text{g} \cdot \text{d}^{-1} \times 24 \text{d}$</td>
<td>□ 1RM BP; ↔ between groups for BW, FFM, % fat</td>
</tr>
<tr>
<td>Burke et al. (5)</td>
<td>Male/female vegetarians age range = 19–55 y; CR = 18; PL = 18</td>
<td>0.25 $\text{g} \cdot \text{kg}^{-1} \times 7 \text{d} \rightarrow 0.0625 \text{g} \cdot \text{kg}^{-1} \times 49 \text{d}$</td>
<td>□ (PCR), ▲ (TCR), ▲ total work for isokinetic knee flexor/extensor strength, ▲ 1RM BP, ▲ FFM; ▲ Type II fiber area</td>
</tr>
<tr>
<td>Ferguson and Syrotuik (13)</td>
<td>Recreationally strength-trained (≥1 y) females age range = 18–35 y; CR = 13; PL = 13</td>
<td>$0.3 \text{g} \cdot \text{kg}^{-1} \times 7 \text{d} \rightarrow 0.03 \text{g} \cdot \text{kg}^{-1} \times 9 \text{wk}$</td>
<td>Both groups ▲ 1RM BP, 1RM leg press and reps to fatigue at 70% 1RM; ▲ FFM; ↔ BW</td>
</tr>
<tr>
<td>Kambis and Pizzeda (21)</td>
<td>College-age females CR = 11; PL = 11</td>
<td>0.5 $\text{g} \cdot \text{kg}^{-1} \times 5 \text{d}$</td>
<td>▲ peak Tq; ↔ between groups for BW, FFM, % fat</td>
</tr>
<tr>
<td>Larson-Meyer et al. (24)</td>
<td>Female collegiate soccer CR = 7; PL = 7</td>
<td>$2 \times 5.7 \text{g} \cdot \text{d}^{-1} \times 5 \text{d} \rightarrow 5 \text{g} \cdot \text{d}^{-1} \times 12 \text{wk}$</td>
<td>▲ 1RM BP and squat; ↔ between groups for BW, FFM, FM, VJ</td>
</tr>
<tr>
<td>Vandenberghe et al. (45)</td>
<td>Sedentary college-age females CR = 10; PL = 9</td>
<td>$4 \times 5 \text{g} \cdot \text{d}^{-1} \times 4 \text{d} \rightarrow 5 \text{g} \cdot \text{d}^{-1} \times 10 \text{wk}$ (training) $→ 5 \text{g} \cdot \text{d}^{-1} \times 10 \text{wk}$ (no training) $→ 0 \text{g} \cdot \text{d}^{-1} \times 4 \text{wk}$</td>
<td>▲ (PCR), ▲ arm flexor Tq, ▲ 1RM leg press, leg extension, and squat, ▲ FFM; ↔ between groups for BW, % fat</td>
</tr>
<tr>
<td><strong>Anaerobic exercise performance</strong></td>
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<tr>
<td>Eckerson et al. (11)</td>
<td>Physically active college-age females; CRP n = 10; CR = 10; PL = 10 (31 males also studied)</td>
<td>$4 \times 5 \text{g} \cdot \text{d}^{-1} \times 6 \text{d}$</td>
<td>CR = 13%; ▲ CRP = 11%; ▲ PL = 1.1%; ↓ in AWC, but N.S. between groups; ↔ for BW between groups; sex effects found</td>
</tr>
<tr>
<td>Eckerson et al. (12)</td>
<td>Physically active college-age females; n = 10; crossover design (CR and PL)</td>
<td>$4 \times 5 \text{g} \cdot \text{d}^{-1} \times 5 \text{d}$</td>
<td>▲ AWC 22%; ↔ BW between treatment</td>
</tr>
<tr>
<td>Kirksey et al. (22)</td>
<td>Male (n = 16) and female (n = 20) collegiate track and field athletes; CR = 15; PL = 21</td>
<td>$22 \text{g} \cdot \text{d}^{-1} \times 6 \text{wk}$</td>
<td>▲ VJ, ▲ mean cycle peak power, mean power output, and total work, ↑ FFM</td>
</tr>
<tr>
<td>Smith et al. (37)</td>
<td>Physically active college-age males (n = 8) and females (n = 7); CR = 7; PL = 8</td>
<td>$4 \times 5 \text{g} \cdot \text{d}^{-1} \times 5 \text{d}$</td>
<td>▲ AWC 10%; ↔ critical power</td>
</tr>
<tr>
<td>Smith et al. (38)</td>
<td>Female collegiate athletes CR = 7; PL = 8</td>
<td>$4 \times 5 \text{g} \cdot \text{d}^{-1} \times 5 \text{d}$</td>
<td>▲ neuromuscular fatigue threshold through PWC&lt;sub&gt;FT&lt;/sub&gt; test; ↔ BW between groups</td>
</tr>
<tr>
<td>Stout et al. (40)</td>
<td>Female collegiate athletes CR = 7; PL = 8</td>
<td>$4 \times 5 \text{g} \cdot \text{d}^{-1} \times 5 \text{d}$</td>
<td>▲ neuromuscular fatigue threshold through PWC&lt;sub&gt;FT&lt;/sub&gt; test; ↔ BW between groups</td>
</tr>
</tbody>
</table>
Table 2  
(continued)

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Design</th>
<th>Exercise parameters</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tarnopolsky and McLennan (43)</td>
<td>Physically active college-age males (n = 12); crossover design (CR and PL)</td>
<td>4 × 5 g·d⁻¹ × 4 d</td>
<td>▲ peak and relative peak anaerobic cycling power; ▲ dorsi-flexion MVC Tq; ▲ (La); no gender effects found</td>
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<tr>
<td>Ziegenfuss et al. (50)</td>
<td>Male and female collegiate athletes; CR = 10; PL = 10</td>
<td>0.35 g·kg⁻¹ FFM × 3 d</td>
<td>▲ total work and peak power during repeated sprint cycling; ▲ BW</td>
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<tr>
<td>Selsby et al. (33)</td>
<td>Male and female collegiate athletes; CR = 10; PL = 10</td>
<td>0.3 g·kg⁻¹ BW × 5 d → 2.25 g·d⁻¹ × 9 d</td>
<td>▲ 100-yl single sprint; ↔ 50-yl sprint or BW between groups</td>
<td></td>
</tr>
<tr>
<td>Cox et al. (8)</td>
<td>Male and female collegiate athletes; CR = 10; PL = 10</td>
<td>4 × 5 g·d⁻¹ × 6 d</td>
<td>▲ sprint and agility; ▲ BW; ↔ shooting accuracy</td>
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<tr>
<td>Dawson et al. (9)</td>
<td>Male and female collegiate athletes; CR = 10; PL = 10</td>
<td>4 × 5 g·d⁻¹ × 5 d → 5 g·d⁻¹ × 22 d</td>
<td>↔ 50- and 100-m single sprint between groups</td>
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<tr>
<td>Grindstaff et al. (17)</td>
<td>Male and female collegiate athletes; CR = 10; PL = 10</td>
<td>3 × 7 g·d⁻¹ × 9 d</td>
<td>▲ swim times for repeated 50- and 100-m sprints; ↔ BW, FFM, FM, % fat, TBW between groups</td>
<td></td>
</tr>
<tr>
<td>Thompson et al. (44)</td>
<td>Female collegiate swimmers (n = 10); CR and PL (group n not reported)</td>
<td>2 g·d⁻¹ × 6 wk</td>
<td>↔ 100- or 400-m single sprint time; ↔ FFM; ↔ PCR resynthesis or mitochondrial ATP synthesis</td>
<td></td>
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<tr>
<td>Mujika et al. (29)</td>
<td>Male (n = 11) and female (n = 9) competitive junior (16 y) swimmers CR = 10; PL = 10</td>
<td>4 × 5 g·d⁻¹ × 5 d</td>
<td>↔ 25- , 50-, or 100-m single sprint times; ↔ (La); ▲ BW</td>
<td></td>
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<tr>
<td>Aoki et al. (1)</td>
<td>College-age females (n = 14); CR and PL (group n not reported)</td>
<td>4 × 5 g·d⁻¹ × 5 d → 3 g·d⁻¹ × 7 d</td>
<td>▲ leg press reps (80% 1RM) after a 20-min aerobic run; ↔ 1RM between groups after the run</td>
<td></td>
</tr>
<tr>
<td>Nelson et al. (30)</td>
<td>Physically active males and females; CR = 6 females, 13 males; PL = 10 females, 7 males</td>
<td>4 × 5 g·d⁻¹ × 7 d</td>
<td>▲ GXT test time; VT; ↓ submax Vo₂; ↓ HR</td>
<td></td>
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<tr>
<td>Smith et al. (36)</td>
<td>Recreationally active males and females; CR = 14 females, 13 males; PL = 14 females, 14 males</td>
<td>4 × 5 g·d⁻¹ × 5 d</td>
<td>↔ Vo₂max, VT, TTE, critical velocity, or BW</td>
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</table>

▲ indicates increase; ↓ indicates decrease; ↔ indicates no change.

% fat = percent body fat; 1RM = 1 repetition maximum; ATP = adenosine triphosphate; AWC = anaerobic working capacity; BP = bench press; BW = body weight; CR = creatine; CRP = creatine phosphate; FFM = fat-free mass; FM = fat mass; GXT = graded exercise test; HR = heart rate; La = lactate; MVC = maximal voluntary contraction; NCAA = national collegiate athletic association; NS = not significant; PCR = phosphocreatine; PL = placebo; PWC_F = physical working capacity at fatigue threshold; TBW = total body water; TCR = total creatine; Tq = torque; TTE = time to exhaustion; VJ = vertical jump; VT = ventilatory threshold.
Creatine as an Ergogenic Aid for Female Athletes

- CR does not impair aerobic exercise performance and may enhance recovery between successive days of training in endurance athletes.
- CR is safe and effective when taken in recommended doses, but should not be taken by individuals with pre-existing kidney or liver problems without their doctor’s consent.
- CR has not been reported to intensify premenstrual symptoms.


REFERENCES


