Creatine supplementation influences substrate utilization at rest

M. ERIK HUSO,1 JEFFREY S HAMPL,1 CAROL S. JOHNSTON,1 AND PAMELA D. SWAN2

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Huso, M. Erik, Jeffrey S Hampl, Carol S. Johnston, and Pamela D. Swan. Creatine supplementation influences substrate utilization at rest. J Appl Physiol 93: 2018–2022, 2002. First published August 16, 2002; 10.1152/japplphysiol.01170.2001.—The influence of creatine supplementation on substrate utilization during rest was investigated using a double-blind crossover design. Ten active men participated in 12 wk of weight training and were given creatine and placebo (20 g/day for 4 days, then 2 g/day for 17 days) in two trials separated by a 4-wk washout. Body composition, substrate utilization, and strength were assessed after weeks 2, 5, 9, and 12. Maximal isometric contraction (1 repetition maximum (RM)) leg press increased significantly (P < 0.05) after both treatments, but 1-RM bench press was increased (33 ± 8 kg, P < 0.05) only after creatine. Total body mass increased (1.6 ± 0.5 kg, P < 0.05) after creatine but not after placebo. Significant (P < 0.05) increases in fat-free mass were found after creatine and placebo supplementation (1.9 ± 0.8 and 2.2 ± 0.7 kg, respectively). Fat mass did not change significantly with creatine but decreased after the placebo trial (−2.4 ± 0.8 kg, P < 0.05). Carbohydrate oxidation was increased by creatine (8.9 ± 4.0%, P < 0.05), whereas there was a trend for increased respiratory exchange ratio after creatine supplementation (0.03 ± 0.01, P = 0.07). Changes in substrate oxidation may influence the inhibition of fat mass loss associated with creatine after weight training.

substrate oxidation; respiratory exchange ratio; carbohydrate; phosphate

A REPORTED EFFECT OF CREATINE supplementation is weight gain (7, 10, 11, 21). Various mechanisms have been proposed, including intramuscular water retention (8, 22) and increased muscle growth (7, 11). Only one known study has assessed the effect of creatine supplementation on substrate utilization. Stroud et al. (20) examined the effect of creatine supplementation (20 g/day for 5 days) on respiratory gas exchange during exercise and 15 min of recovery. Subjects ran on a treadmill at 50–90% maximal O2 consumption for 6 min at each of five intervals while gas samples were collected during the final 30 s at each workload. The results indicated that creatine had no effect on respiratory gas exchange during exercise or recovery. The authors explained that the measurements could have been too insensitive to quantify the small changes in metabolic measures during exercise and recovery that could potentially occur with creatine supplementation. There may be other factors that confound the measurement of substrate utilization after acute exercise, such as lactate concentration, that may mask any change in substrate. Thus a more steady-state measurement, such as during rest, is needed.

The effect of creatine supplementation on substrate utilization at rest has not been sufficiently investigated. Because fat is the primary fuel oxidized during inactivity, measuring the respiratory exchange ratio (RER) at rest could indicate whether fatty acid oxidation is suppressed as a result of elevated levels of creatine phosphate in the system. A shift in substrate utilization toward lower fat oxidation could lead to a concomitant change in body composition with increased body fat stores. On the basis of anecdotal evidence of weight gain, including a lack of fat loss, in persons taking creatine, a four-person pilot study was carried out to determine whether creatine had any effect on substrate utilization. The results were encouraging, which led the authors to pursue the present study. Thus we hypothesized that creatine supplementation would result in a shift in substrate utilization at rest toward greater carbohydrate oxidation and less fat oxidation, indicated by a rise in the RER.

METHODS

Subjects. In a double-blind, placebo-controlled crossover design, 10 healthy, nonsmoking, recreationally active male subjects (Table 1) were recruited from a campus population (Fig. 1). All subjects were free from chronic diseases and were not regularly taking prescription medications. Moreover, all subjects participated in moderate physical activity at least three times per week, were not vegetarians, were not taking any ergogenic aids, and had never supplemented with creatine. The study was approved by the Human Subjects Institutional Review Board at Arizona State University, and all subjects gave their voluntary and informed consent before participation.

Diet. Subjects were instructed to maintain their normal diet throughout the study, except to limit consumption of caffeinated beverages to two or fewer servings per day. Ran-

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dom 24-h recalls were conducted via telephone at baseline and once during each test period to ensure that dietary intake remained normal. Food records were reviewed by a registered dietitian and analyzed using the Genesis R&D software (version 6.01, 1997, Esha Research, Salem, OR).

Exercise. Before initiation of creatine supplementation, subjects participated in a familiarization session and 2 wk of weight training. Subjects were then tested twice to determine baseline 1 repetition maximum (RM) for bench press and leg press. All 1-RM tests were performed on the same equipment (CYBEX International, Medway, MA) and overseen by the same trained technician. Subjects followed an exercise program adapted from a protocol previously shown to increase strength and body mass in subjects supplementing with creatine and/or placebo (21) (Table 2).

Respiratory measures. On the evenings before all RER testing (end of weeks 2, 5, 9, and 12), subjects consumed the same self-selected meal to standardize the immediate effect of diet on respiratory exchange. Subjects were instructed to avoid all food and drink (excluding water) for 12 h until the morning RER measurement. No subjects exercised within 24 h of their RER test.

Subjects were tested between 5 and 9 AM, and each individual subject was tested at the same time of day for each trial. On arrival at the laboratory, subjects were positioned in a reclining chair and habituated to the open-circuit spirometry metabolic analysis apparatus for 20 min. A respiratory mask was placed over the subject’s face and carefully checked and sealed to prevent air leakage. Before subject testing, the O\textsubscript{2} and CO\textsubscript{2} analyzers were calibrated by N\textsubscript{2} and two primary standard gases accurate to 0.01%. The pneumotachometer was calibrated using a 3-liter syringe to deliver standard gases accurate to 0.01%. The pneumotachometer was calibrated using a 3-liter syringe to deliver standard gases accurate to 0.01%. The pneumotachometer was calibrated using a 3-liter syringe to deliver standard gases accurate to 0.01%.

Twenty-four-hour urine samples were collected before each RER measurement. Urine was analyzed for urea nitrogen and creatinine by colorimetric spectrophotometry to measure any changes in total body protein mass, to determine creatine uptake on the basis of the assumption that urinary creatinine clearance increases proportionally to muscle creatine uptake (8), and to allow for the protein RER determination. The samples were collected, stored, and analyzed by standard laboratory kits (Sigma Chemical, St. Louis, MO).

Body composition. Baseline body weight and body density were determined using whole body plethysmography (Bod Pod, Life-Measurement Instruments, Concord, CA). The Bod Pod uses whole body densitometry to determine body fat percentage using the Siri equation (2). The Bod Pod has been shown to be a reliable and valid tool for measuring body composition (2, 3, 12, 13). Subjects were directed to wear a Lyca swim cap and tight-fitting Lyca/spandex shorts or swimming briefs for each trial. Measurements were taken according to standard manufacturer procedures (2, 12). Additionally, lung volume was measured using a mouthpiece and tube. The initial lung volume was used for each subsequent test. All tests were performed by the same technician immediately after the RER test.

Creatine supplementation. In a double-blind manner, subjects were randomly assigned creatine monohydrate powder

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<th>Table 1. Baseline physical characteristics of subjects</th>
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Values are mean ± SE (n = 10). BMI, body mass index.
(a gift from X-Rated, Hi-Health, Scottsdale, AZ; 20 g creatine/day for 4 days, then 2 g creatine/day for 17 days) or a placebo similar in appearance and taste (20 g maltodextrine for 4 days, then 2 g for 17 days). Subjects were instructed to mix the powder in juice or water. Also, subjects were required to participate in resistance training at least three times per week and to keep a workout log. Subjects were required to submit their workout logs, and compliance was determined by the trained technician.

At the end of 3 wk, subjects were tested for changes in 1-RM bench and leg press, body composition, and RER. After a 4-wk washout period (6, 8), where supplementation was terminated but exercise continued, subjects were reassigned creatine or placebo and were tested again for a baseline measurement. After 3 wk of creatine or placebo, subjects returned to the laboratory for testing (Fig. 1).

Statistics. Values are means ± SE. Data analyses were performed on the Statistical Package for the Social Sciences for Windows (version 10.0, 2000, SPSS, Chicago, IL). A general linear model repeated-measures analysis was used to compare differences between means over the course of the study. Order effects were determined by using a "dummy" variable and assessing a trial-by-time interaction in the model. Post hoc comparisons were done by least significant differences because of the small number of pairwise comparisons. P < 0.05 was considered significant.

RESULTS

No negative side effects were reported in subjects taking creatine. For all measures, order effects were examined but were never significant. Energy intakes remained consistent throughout the duration of the study. With 3 wk of creatine supplementation, body mass increased significantly from 73.6 to 75.2 kg, a 2.2% increase (P < 0.05). There was no significant change in body mass during placebo use (Table 3).

Body composition. Fat-free mass (FFM) increased after the weight-lifting program regardless of treatment from 63.1 to 65.0 kg with creatine (P < 0.05) and from 63.2 to 65.4 kg with placebo (P < 0.01). No significant differences in fat mass (FM) or percent body fat were observed in the creatine group. However, percent body fat (from 15.6 to 12.4%, P < 0.01) and FM (from 12.0 to 9.6 kg, P < 0.05) decreased significantly during placebo use.

Strength. Subjects in the creatine group experienced significant increases in strength with bench press (from 87 to 91 kg, P < 0.01) and leg press (from 280 to 313 kg, P < 0.01), whereas subjects on placebo had significant increases only with leg press (from 300 to 314 kg, P < 0.05).

DISCUSSION

Previous research has indicated that subjects taking creatine supplements experienced a significant increase in weight gain (4, 11, 21). Researchers have looked to identify the source of weight gain to determine whether it is due to an increase in FFM or merely an increase in water (7). In accordance with existing data, body mass increased significantly in subjects taking creatine during the course of this study. Significant gains in FFM were shown after both treatments; however, only the placebo group lost a significant amount of FM and showed a significant decrease in percent body fat. The ratio of FM to FFM significantly decreased during the placebo trial but not during the creatine trial. Thus this study supports earlier studies.
that creatine supplementation increases body mass with resistance training and indicates that creatine supplementation does not enhance percent body fat loss in recreationally active men (4, 11, 15, 21). The placebo group experienced the expected response to resistance training (16), i.e., they became leaner, whereas the creatine group experienced an inhibition of this expected fat loss.

Francaux and Poortmans (7) proposed that increased myosin synthesis could be the mechanism behind the ergogenic effect of creatine on exercise. However, our data show that the increase in FFM was similar in subjects taking creatine or placebo. In addition, those supplementing with creatine experienced significantly greater gains in 1-RM bench press and leg press. Therefore, although it was not measured directly, we deduce that the ergogenic effect of creatine on exercise performance must be from a mechanism other than increased myosin synthesis.

Consistent with these body composition data, we also found a trend for change in RER (P = 0.07) that supports the difference in FM between the creatine and placebo groups. (Post hoc power analysis indicated that a sample of 12 would have been needed for statistical significance.) Although there was no significant change in RER during placebo administration, the increase in RER among creatine subjects approached statistical significance, indicating that subjects utilized a greater percentage of carbohydrate than fat during creatine supplementation. The difference in carbohydrate oxidation before vs. after creatine was significant (P = 0.05; Fig. 2). This finding is notable, inasmuch as it is the first time that the effect of creatine on resting RER has been examined.

At the onset of exercise, with resistance training, and during transitions from lower to higher intensity exercise when energy demand is greater than energy production from aerobic sources, creatine phosphate is a readily available short-term fuel to produce ATP. The products of creatine phosphate hydrolysis include free creatine and Pi. Pi is a key activator of the phosphofructokinase enzyme, promoting glucose oxidation (1). The increased flux of glucose oxidation results in increased levels of malonyl-CoA (23).

Malonyl-CoA is a known regulator of fatty acid oxidation (9, 19, 23). As the first committed intermediate of fatty acid synthesis, malonyl-CoA is a powerful inhibitor of the carnitine palmitoyltransferase (CPT I) enzyme system responsible for shuttling fatty acids into the mitochondria for oxidation (17, 23). When glucose levels decline, malonyl-CoA also declines, allowing for increased fatty acid oxidation. Concentrations of malonyl-CoA drop during exercise and in the fasted state, relieving the inhibition of CPT I. This decrease in CPT I allows for an increased rate of fatty acid oxidation as fats become available (23). The depletion of ATP stores and subsequent increase in Pi during activity result in an activation of the enzyme phosphofructokinase, causing an influx of carbohydrate to be oxidized. The infusion of glucose into exercising rats has been shown to terminate the decline in malonyl-CoA (5). Therefore, a promotion of glucose oxidation from elevated levels of Pi could in theory suppress fatty acid oxidation. However, research has shown that Pi levels return to normal in the rested state after creatine loading (18).

A more likely rationale would be the improved insulin sensitivity and antihyperglycemic activity that creatine analogs have been shown to possess (14). Although the mechanism is unknown, 3-guanidinopropionic acid administered to KKAy mice (a non-insulin-dependent diabetes mellitus model) resulted in augmented glucose uptake by the muscle tissue (14). As a guanidino analog to 3-guanidinopropionic acid, elevated levels of creatine could potentially exert a similar glycemic response, resulting in increased carbohydrate utilization by muscle tissue at rest.

In conclusion, subjects supplementing with creatine experienced greater gains in 1-RM bench press, 1-RM leg press, and weight gain than those using placebo. We found that the increase in FFM was nearly identical in subjects taking creatine or placebo. However, the results demonstrate that individuals taking creatine may reduce their ability to lose FM in response to exercise training. The results suggest that creatine loading may inhibit the normal fat loss that occurs in healthy active men implementing a strength-training program. Moreover, for the first time, it was shown that creatine supplementation led to a trend for increased RER at rest, a potential mechanism for the impaired fat loss. These conclusions affirm our hypothesis that creatine supplementation would result in a shift in substrate utilization at rest toward greater carbohydrate oxidation and less fat oxidation, indicated by a rise in the RER. Although there are ergogenic benefits from creatine supplementation, athletes participating in wrestling, swimming, gymnastics, and other weight-sensitive sports should first consider the potentially negative side effect of fat retention before choosing creatine supplementation.

**Fig. 2.** Percent participation of a substrate in total energy utilization. *P < 0.05, pre-creatine vs. post-creatine carbohydrate.
REFERENCES


