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ORIGINAL ARTICLE

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Effect of creatine feeding on maximal exercise performance in vegetarians

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Abstract The effect of creatine supplementation on exercise performance in vegetarians was examined. Creatine was ingested for 1 week by a group of vegetarians (VC) and meat-eaters (MC); a control group of meat-eaters was fed only glucose (MG). Exercise performance during three, 20-s maximal cycling tests (modified Wingate anaerobic test, WAnT) was determined before and after creatine supplementation. Blood samples were also drawn before and after exercise prior to and after supplementation. Basal plasma creatine (after an overnight fast) averaged (SE) 11 (2) μM in VC, and 24 (2) and 23 (7) μM in MG and MC, respectively ($P < 0.05$ for VC vs meat-eaters). These findings were expected, since most of the body's exogenous creatine source is meat. There was no significant difference in any other parameter between groups prior to supplementation. Creatine feedings significantly increased body mass (≅1 kg) and mean power output during the WAnTs (≅5%) to a similar extent in the VC and MC groups ($P < 0.05$–0.001). These parameters were not affected by supplementation in the MG group. Peak power output was also significantly increased by supplementation in MC (≅5%, $P < 0.05$), but not in VC. It is concluded that vegetarians and meat-eaters respond to creatine feedings with similar increases in mean power output during short-term, maximal exercise.

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Introduction

The ability to perform maximal exercise is of practical importance, be it for daily function, recreational/competitive sports, or military action. The increased popularity of maintaining a vegetarian diet, despite many of the health benefits, may be associated with a decreased maximal exercise capacity (see below). It is therefore important to determine maximal exercise capacity in this population, and to evaluate practical methods to improve it.

Fatigue during short-term, intense exercise is associated with the depletion of phosphocreatine (PCr) in muscle (Katz et al. 1986; Sahlin et al. 1998). It follows that an increase in the content of PCr should enhance maximal exercise performance, although the effect of PCr on maximal force may be indirect. Since PCr is generated by the phosphorylation of creatine (Cr), increasing the muscle Cr content should result in increased levels of PCr and enhanced performance. Indeed, recent studies show that ingestion of Cr results in both (Birch et al. 1994; Balsom et al. 1995; Casey et al. 1996; Vandenberghe et al. 1996; Brannon et al. 1997). A significant portion of the body's Cr stores is obtained through diet, particularly red meats, which are relatively rich in Cr (Balsom et al. 1994). Because foods ingested by vegetarians contain relatively low contents of Cr, vegetarians may have lower body Cr levels, and may be at a disadvantage in events requiring high energy-turnover rates. Indeed, vegetarians have lower serum and erythrocyte Cr concentrations than do meat-eaters (Delange et al. 1989), although the muscle concentrations have not been systematically studied. Individuals that have low Cr and PCr contents in muscle respond with larger increases in muscle Cr and PCr contents after ingesting Cr than do individuals with normal muscle Cr and PCr (Harris et al. 1992). Therefore, it is possible

that vegetarians also respond with larger increases in muscle Cr and PCr than do meat-eaters. Consequently, vegetarians may respond to Cr feedings with relatively greater increases in performance than do meat-eaters. The purpose of this study was to determine the effect of Cr feeding on maximal exercise performance in vegetarians.

Methods

Subjects

Twenty-four healthy, active, but not highly trained men (17 meat-eaters and 7 vegetarians) participated in the study (Table 1). The subjects were informed of the possible risks involved in the study before giving their voluntary consent to participate. The experimental protocol was approved by the University Hospital (Tel-Hashomer Medical Center) Ethical Committee.

Protocol

A single blind (subjects were unaware), placebo-controlled study was performed. Meat-eaters who ingested glucose (MG, $n = 8$) over a 6-day period (3×5 g day^{-1}) served as controls for any effect of Cr supplementation. Other meat-eaters ingested Cr (MC, $n = 9$) over a 6-day period (3×7 g day^{-1}). Each Cr dose (7 g) was mixed with 5 g of glucose. The vegetarians (VC, $n = 7$) received the same Cr/glucose mixture as the MC group. Subjects were instructed to dissolve the glucose or Cr + glucose powders in about 300 ml of a warm beverage. A commercial preparation of Cr (claimed to be 99% pure; Eurolink, Tel-Aviv, Israel) was given to the subjects, and our analyses (see below for method) showed that it was >95% pure by weight.

Subjects reported to the laboratory after an overnight fast on two occasions. Subjects in all three groups were instructed to dissolve one teaspoon of table sugar in a cup of warm water and drink it 1 h before the first experiment (since this was also performed prior to the second experiment). A polyethylene indwelling catheter was inserted into an antecubital vein and 3 ml of blood was drawn. Subjects then performed a modified Wingate anaerobic test (WAnT; Bar-Or 1987), which consisted of three 20-s bouts of maximal cycling exercise with 4 min of recovery between bouts (2 min of low-load cycling followed by 2 min in the supine position). Briefly, the WAnT was performed on a computerized cycle-ergometer (Fleisch Metabo Ergostat Universel, Lausanne, Switzerland). Subjects warmed-up for 5 min at a pedaling rate of 60–70 rpm against a resistance equal to 20% of that calculated for the subsequent WAnT. Two unloaded 5-s sprints were performed at the end of the 3rd and 5th min of the warm-up period. The maximal pedaling rate (rpm_{max}) attained during the sprints was recorded. Following a 5-min rest, subjects performed the WAnT against a resistance of 0.052 kg · kg · body mass^{-1} (5.13 J · pedal revolution^{-1} · kg body mass^{-1}). Subjects were instructed to pedal as fast as possible from the onset of the test. The resistance was applied when 75% of the previously recorded rpm_{max} was attained. Subjects were verbally encouraged to maintain as high a pedaling rate as possible throughout the 20-s test duration. Pedal revolutions were monitored at a resolution of 0.025 revolutions, and recorded at 1-s intervals. Mean power ($\bar{W}$) was the average power generated throughout the 20-s test. Additional blood was drawn just before bouts 2 and 3, and 5 min after the last bout. Thereafter, the subjects received their supplements, aliquoted in plastic bags. They were instructed to take their supplements twice on the day of the first trial, then 3 times per day for the next 5 days. On the 6th morning, 1 h before the second trial, the subjects consumed their last supplement (dissolved in warm water). The experimental protocol of the first trial was then repeated.

Table 1 Physical characteristics of the subjects. Values are means (SE) for seven to nine subjects per group. (*MC* Meat-creatine group, *VC* vegetarian-creatine group, *MG* meat-glucose group, *Before* before supplementation, *After* after supplementation)

Group	Age (years)	Height (cm)	Body mass (kg)	
			Before	After
MC	26.1 (0.6)	177 (2)	75.6 (4.3)	76.7 (4.3)**
VC	29.6 (2.7)	175 (2)	70.3 (2.6)	71.4 (2.7)**
MG	27.4 (1.9)	175 (2)	74.2 (2.6)	74.2 (2.6)

** $P < 0.01$ versus Before (paired t-test)

Analyses

Power outputs and calculation of the degree of fatigue during exercise were determined as described elsewhere (Bar-Or 1987). Blood samples were ejected into tubes containing ethylenediaminetetraacetic acid, stored on ice, and centrifuged in a clinical centrifuge at 3000 *g*. Plasma was aspirated and stored initially at −30 °C, and subsequently at −80 °C until analysis. For analysis of Cr, an aliquot of plasma was deproteinized with an equal volume of ice-cold 0.6 M perchloric acid. The extract was centrifuged and the supernatant was neutralized with 2.2 M $KHCO_3$, and then centrifuged again. The neutralized extract was analyzed for Cr, and the plasma was analyzed for glucose and lactate with enzymatic, fluorometric techniques based on changes in NAD(P)H (Lowry and Passonneau 1972).

Statistics

Values are presented as the mean (SE), unless indicated otherwise. Statistically significant differences between means ($P < 0.05$) were determined with the paired or unpaired t-test, or a one-way repeated measures analysis of variance where appropriate.

Results

There were no significant differences in any variable between the MC and MG groups prior to Cr supplementation. Therefore, the results of these two groups were pooled and then compared with the results of the VC group for all variables measured prior to supplementation. There were no significant differences between VC and meat-eaters for any measured variable, with the exception that plasma Cr concentration was lower in the vegetarians [VC = 11 (2) μM; meat-eaters = 23 (4) μM, $P = 0.01$].

None of the measured variables was altered by the placebo feedings in MG. The insignificant increase in $\bar{W}$ after placebo supplementation of 1–2% indicates the good reproducibility of our protocol (Fig. 1). Cr supplementation resulted in an increased body mass (Table 1) and $\bar{W}$ during the WAnT (Table 2). The improvement in $\bar{W}$ was about 5% in both MC and VC (Fig. 1). In addition, Cr supplementation increased peak power output (usually seen within the first 5 s of cycling) in MC (≅5%), but not in VC (Table 2). Fatigue was generally unaffected by Cr supplementation, with the exception of an improvement after the second exercise bout in VC (Table 2).

Plasma glucose and lactate responses to the WAnT before and after Cr supplementation were comparable in both MC and VC, with the exception that lactate was significantly higher after the third exercise bout in MC after supplementation (Table 3). Plasma Cr concentrations were markedly elevated after Cr supplementation in both VC and MC (Fig. 2). This indicates that the subjects indeed ingested their supplements. There were no significant changes in plasma Cr during repeated exercise bouts after Cr supplementation (Fig. 2), suggesting that the release of free Cr from muscle after exercise is negligible. Similar analyses (before and after exercise) before Cr supplementation in MC and VC, and in the MG group (before and after supplementation) were attempted. However, the large increases in plasma pyruvate after exercise compared to the relatively low levels of plasma Cr made accurate analyses of Cr problematic (data not shown).

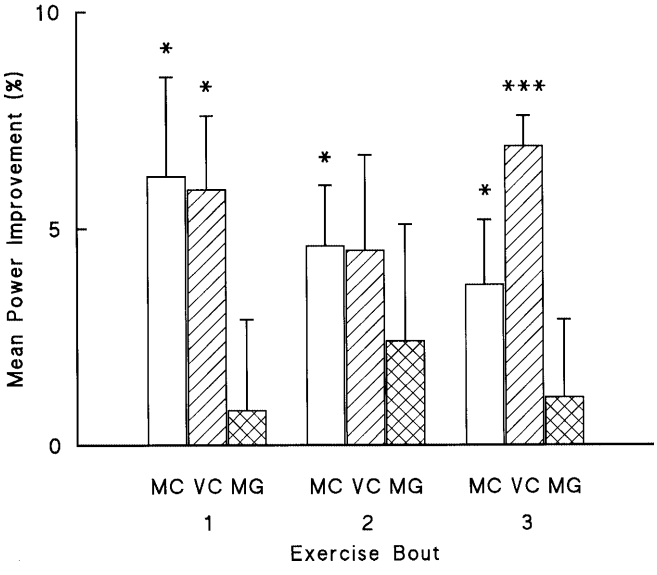

Fig. 1 Improvement in mean power output during the modified Wingate anaerobic test after creatine (Cr) (or glucose) supplementation. Values are means ±SE for six to nine subjects per group ($n = 5$ for bout 3 in the VC group). (*MC* Meat-creatine group, *VC* vegetarian-creatine group, *MG* meat-glucose group). *$P < 0.05$; ***$P < 0.001$ versus pre-supplementation (paired *t*-test)

Discussion

The results of this study confirm that Cr feedings enhance performance during intense, short-term exercise, and that the improvement is ≅5% (c.f. Birch et al. 1994; Casey et al. 1996). The hypothesis that vegetarians have a lower maximal exercise capacity, and that this can be improved to a relatively larger extent by Cr feedings was not substantiated. Although we confirmed that plasma Cr concentrations were lower in VC prior to Cr supplementation (c.f. Delange et al. 1989), this may not reflect a lower intracellular Cr concentration in vegetarians. The fact that the erythrocyte Cr concentration is

Table 3 Plasma glucose and plasma lactate responses to exercise. Values are means (SE) for five to nine subjects per group

Group	Glucose (mM)		Lactate (mM)	
	Before	After	Before	After
MC				
Rest	4.7 (0.2)	4.5 (0.4)	0.8 (0.1)	1.2 (0.2)
Bout 1	5.1 (0.2)	5.3 (0.3)	8.5 (0.9)	9.5 (1.4)
Bout 2	5.8 (0.4)	5.5 (0.3)	12.5 (1.0)	13.3 (1.0)
Bout 3	6.1 (0.5)	6.1 (0.3)	13.6 (0.7)	15.4 (1.1)*
VC				
Rest	4.8 (0.2)	4.7 (0.2)	0.9 (0.1)	0.9 (0.2)
Bout 1	5.6 (0.5)	5.0 (0.1)	10.2 (1.2)	8.6 (0.8)
Bout 2	5.6 (0.3)	5.2 (0.2)	13.0 (1.8)	11.0 (1.4)
Bout 3	5.9 (0.4)	5.3 (0.3)	15.8 (2.3)	12.7 (1.3)
MG				
Rest	4.4 (0.1)	4.6 (0.2)	1.0 (0.2)	1.4 (0.4)
Bout 1	5.5 (0.6)	4.9 (0.2)	10.0 (2.0)	9.9 (2.2)
Bout 2	5.2 (0.3)	5.0 (0.2)	12.2 (1.8)	12.6 (2.1)
Bout 3	5.0 (0.2)	5.0 (0.2)	12.7 (0.7)	12.9 (1.1)

* $P < 0.05$ versus Before (paired *t*-test)

Table 2 Results of the modified Wingate anaerobic test. Values are means (SE) for six to nine subjects per group ($n = 5$ for bout 3 in VC group)

Group	Mean power (W)		Peak power (W)		Fatigue (%)	
	Before	After	Before	After	Before	After
MC-Bout						
1	1021 (71)	1089 (86)*	1114 (72)	1186 (89)*	20 (2)	19 (3)
2	981 (72)	1029 (82)*	1077 (69)	1129 (83)*	21 (3)	21 (3)
3	955 (76)	992 (81)*	1057 (66)	1103 (75)*	24 (4)	24 (4)
VC-Bout						
1	903 (69)	951 (63)*	1015 (64)	1037 (68)	24 (3)	20 (3)
2	884 (79)	919 (75)***	982 (69)	999 (80)	25 (4)	19 (3)*
3	804 (71)	859 (78)**	899 (48)	951 (68)	26 (6)	23 (1)
MG-Bout						
1	949 (42)	957 (48)	1041 (44)	1046 (53)	21 (3)	21 (2)
2	903 (63)	920 (59)	1013 (57)	1023 (61)	26 (6)	24 (5)
3	933 (54)	938 (43)	1027 (59)	1055 (46)	22 (4)	24 (5)

*** $P = 0.07$; * $P < 0.05$; ** $P < 0.01$ versus Before (paired *t*-test)

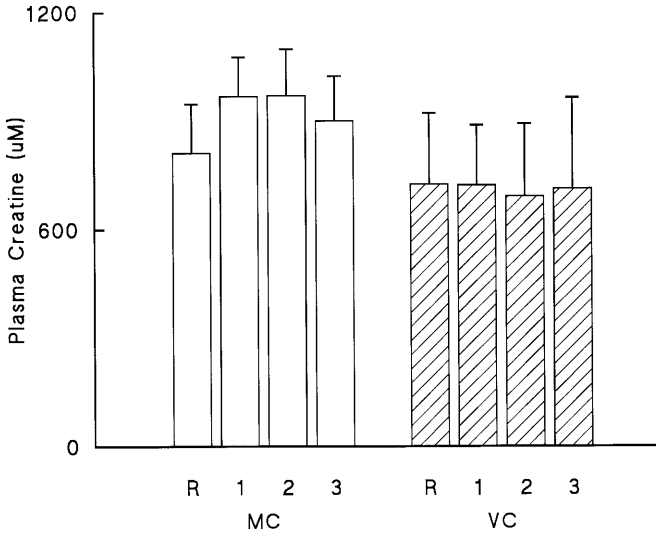

Fig. 2 Exercise does not alter plasma Cr concentration. Values are means ± SE for five to nine subjects. (*R* Rest, *1–3*, exercise bouts 1–3, respectively). Statistical analyses were by performed by one-way repeated-measures analysis of variance on samples obtained after Cr supplementation

also lower in vegetarians than in meat-eaters (Delange et al. 1989) does not mean that the Cr concentration in the tissue of interest (i.e., skeletal muscle) is also lower. Indeed, the erythrocyte Cr concentration is only about 0.4 mM, whereas the muscle free Cr concentration at rest is ≅40-fold higher (assuming 3 l intracellular water·kg dry muscle^{-1} and 45 mmol of free Cr·kg dry muscle^{-1}). Moreover, the erythrocyte free Cr content amounts to less than 1% of the total skeletal muscle free Cr pool (assuming that muscle accounts for 40% of body mass). Therefore, differences in circulating Cr concentrations may not reflect differences in muscle Cr concentrations. Hence, it is possible that the Cr (and PCr) levels in VC muscle prior to supplementation were similar to those of the meat-eaters, and that the increases in muscle Cr and PCr concentrations observed after Cr supplementation were comparable in MC and VC. Indeed, no clear differences in the contents of PCr + Cr in muscle prior to Cr supplementation, and the increase after supplementation were seen between meat-eaters and two vegetarians (Harris et al. 1992). Nevertheless, conclusions on the PCr and Cr contents in the muscle of vegetarians warrant direct measurements in a larger number of subjects.

The enhanced $\bar{W}$ observed during repeated bouts of 30 s of intense cycling subsequent to Cr supplementation is sometimes associated with a significant increase in peak power output (Birch et al. 1994), and sometimes not (Casey et al. 1996). The increase in $\bar{W}$ observed in the present study was associated with an increase in peak power output in MC. Surprisingly, this was not the case with the VC group, who showed no significant increase in peak power output following Cr supplementation, despite improvements in $\bar{W}$. We have no explanation for this finding at present.

Blood lactate levels after intense exercise following Cr supplementation have been reported to be increased (Balsom et al. 1993a), unchanged (Birch et al. 1994), or even decreased (Balsom et al. 1993b). The reason for such inconsistent results is unclear. While plasma lactate after the last exercise bout was significantly higher after Cr supplementation in MC, there was no significant difference in VC. Indeed, there was a trend for plasma lactate concentrations to be lower after Cr supplementation in VC.

While the beneficial effects of Cr supplementation on maximal exercise performance appear to be well established, the effects on diseased states and side effects are not as clear. Chronic Cr feedings for 1 year have been shown to attenuate the progression of gyrate atrophy of the choroid and retina, and to increase the diameter of type II muscle fibers in these patients (Sipilä et al. 1981). Adverse effects of Cr feedings have generally not been noted (Balsom et al. 1994). However, the recent report that Cr supplementation appears to result in renal function deterioration in a patient with a history of renal disease (Pritchard and Kaira 1998) warrants additional research on the effects of Cr in health and, particularly, disease.

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