

ABSTRACT

LUTHER, H. C. Effects of creatine monohydrate supplementation on muscular strength and body composition. MS in Exercise and Sport Science-Human Performance, December 1997, 33pp. (J. Porcari)

The purpose of this study was to determine if using a new form of creatine monohydrate (Phosphagens - EAS) could increase muscular strength and favorably alter body composition. Twenty-seven college-aged Ss were randomly placed into a placebo or creatine group. Subjects in the creatine group were required to ingest 20 grams maintenance of the supplement for 5 days (loading phase) and 5 grams everyday thereafter (phase), while the placebo group took an identical looking and tasting product. The supplement or placebo was distributed in a double-blind protocol. Ss performed 1 RMs for the bench press and squat, and body composition was measured using hydrostatic weighing before and after supplementation/training. For the training program, both groups participated in a 6 week, 4 day split, resistance training program. Supplementation began the first week of the resistance program. The posttests were performed the week following the completion of the resistance program. Data were analyzed using a 2-way ANOVA with repeated measures and a Tukey's post hoc test. Both groups increased significantly ($p < .05$) in bench press and squat strength. The placebo group increased 22.9 lbs in the bench press and 59.6 lbs in the squat, while the creatine group increased 30.0 lbs in the bench press and 46.2 lbs in the squat in 6 weeks. Differences between groups were not statistically significant ($p > .05$). Total body and lean body weight increased significantly in the creatine group only ($p < .05$). Total body weight increased 5.4 lbs, with 4.8 lbs being lean body weight. No changes were found in % body fat or fat weight in either group. The results of this study indicate that creatine monohydrate does not improve muscular strength and/or body composition. However, the results of this research suggest that through a scientifically sound resistance training program, significant strength gains will occur along with slight improvements in body composition. Further research with the effects of creatine supplementation on muscular strength and body composition is needed.

EFFECTS OF CREATINE MONOHYDRATE SUPPLEMENTATION
ON MUSCULAR STRENGTH AND BODY COMPOSITION

A MANUSCRIPT STYLE THESIS PRESENTED
TO
THE GRADUATE FACULTY
UNIVERSITY OF WISCONSIN-LA CROSSE

IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
MASTER OF SCIENCE DEGREE

BY
HAROLD C. LUTHER II
DECEMBER 1997

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UNIVERSITY OF WISCONSIN-LA CROSSE

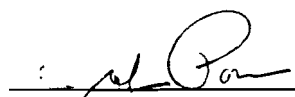
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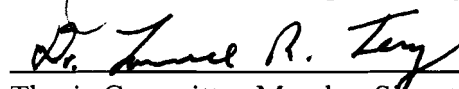
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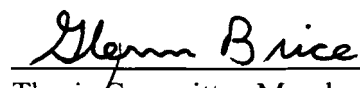
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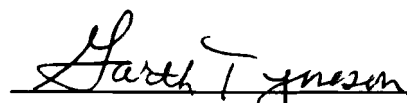

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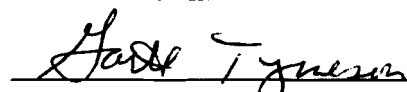

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INTRODUCTION

Success in competition has become the main focus of athletes throughout the world. Society looks to successful figures in the sports arena. This concept has driven the athlete to train harder, be more devoted, and experiment with new techniques to better their abilities. This mentality has continued throughout history based on the premise that records are constantly being set and broken in all fields of sport. New strength training systems, precise diets, and mental visualization techniques are constantly being developed to obtain the winning edge that seems to be the crucial component in competition. In all aspects of human muscle performance, limits are defined and set including strength/power, speed, endurance, hypertrophy, and protein synthesis. With intense training, adequate recovery, and proper nutritional supplementation, all of these can be adjusted upward.

Over the years, science and technology have been attempting to raise the upper limits of physical performance through the use of ergogenic aids. A great amount of research has been done to determine the reliability and validity of such aids. Many athletes look to nutritional manipulation to improve performance (3). Any type of nutritional manipulation is technically classified as an ergogenic aid.

Creatine monohydrate, which is creatine in its purest form, has become

a popular ergogenic aid for the strength/power athlete. In 1832, Chevreul, a French scientist, reported the finding of a new organic constituent of meat to which he gave the name "creatine". However, due to problems with the method for detecting creatine, it was not until 1847 that Lieberg was able to confirm that creatine was a regular constituent of flesh extracted from mammals. Early in the twentieth century, numerous studies with creatine feeding were carried out. It was observed that not all of the creatine ingested could be recovered from the urine, which suggested that some of the creatine was retained in the body according to Balsom et al. (2). The total creatine pool in humans refers to the combined amount of creatine in its free and phosphorylated form.

Approximately 95% of the total creatine pool in humans is found in skeletal muscle, where creatine phosphate accounts for approximately two-thirds of the total creatine pool. A person's daily turnover of creatine is approximately 2-g per day, which is replaced through both endogenous and exogenous sources (5). In distinguishing between type I and type II skeletal fibers, type II fibers have been shown to have a higher level of creatine phosphate than type I (2). Type II fibers utilize creatine more than type I fibers due to the fact that creatine phosphate is the primary energy source for the phosphogenic system.

The phosphogenic system is anaerobic (without oxygen). For this reason, energy must be produced another way. This is where the ATP-PC system comes into play. During high-intensity activity, ATP is broken down to ADP, adenosine

diphosphate. From this break, energy is produced and ADP is the by-product. Once all the ATP in the system is broken down to ADP, the high energy phosphate in PC is transferred to the ADP to form ATP and the process can continue. The purpose for creatine supplementation is to allow this process to continue longer, thus facilitating longer exercise bouts and at higher intensities. With longer, intense exercise bouts, the subject will become stronger, faster, and more powerful.

As early as 1923, Macht observed "some kind of beneficial effect" upon motor control of rats running in a maze after a period of creatine supplementation. Greenhaff (6) and colleagues report that a 5 day period of creatine supplementation at 20-g per day increased the ability to produce muscle torque during five bouts of 30 maximal voluntary knee extensions, interspersed with 60-s rest periods. Other studies have shown significant changes in muscular strength, anaerobic power and capacity, and body composition through the use of creatine monohydrate (1, 3, 4, 6, 7, 9). As with any ergogenic aid, questions arise concerning side effects. To date, no serious side effects have been reported. Anecdotally, cramping, gastrointestinal discomfort, and increased urination are the only side effects to be mentioned (3, 7, 8, 9).

The purpose of this investigation was to determine if creatine monohydrate, as an ergogenic aid, enhances muscular strength and improve body composition. This information would add to the validity of using creatine as a nutritional supplement to enhance athletic performance. This study presents a slightly different approach.

indicate the ability to maintain maximum output repeatedly. Few studies have focused on improving a subject's strength or body composition.

METHODS

Thirty male subjects were recruited from the University of Wisconsin-La Crosse (UW-L) Strength Center and served as voluntary subjects. The protocol was approved by the Institutional Review Board (IRB) for the protection of Human Subjects before the study began. In accordance with the guidelines set forth by the IRB, each subject received a full explanation of the testing, training, and supplementation procedures and signed an informed consent form prior to participation in the study (see Appendix A). Subjects were selected with the understanding that all subjects were intermediate to advanced resistance trainers. This was defined by being involved in an intense resistance training program for at least 3 months prior to the beginning of the study. An intense resistance program was defined as a 4 day per week, push-pull type of program using some form of periodization. Subjects were accepted with the understanding that all subjects had never ingested creatine monohydrate or had not done so for at least one year prior to the beginning of this study. Subjects were requested to be medication free and were assumed to be in good health. Finally, no subjects were to be active intercollegiate athletes (on a roster). Subjects were also accepted with the understanding that they would be randomly assigned to one of two groups, an experimental (creatine) or a control (placebo) group. However, the subjects were not aware of group assignment.

groups, an experimental (creatine) or a control (placebo) group. However, the subjects were not aware of group assignment.

Experimental Protocol and Data Collection

Data collection involved two phases: pretesting and posttesting. Both groups were tested identically and tested together. Subjects were tested for 1 RM in the bench press and squat. These tests were conducted in the Mitchell Hall Strength Center at the UW-L. Body composition was tested using the hydrostatic weighing technique. This test was conducted in the Human Performance Laboratory at the UW-L. Residual volume (RV) of the subject was measured while the subject was submerged to the neck in water. Once RV was measured, subjects performed approximately six trials of underwater weighing. The two closest scores were averaged and used to determine body density (BD). The appropriate information (BD) was then used to predict percent body fat. The testing protocol remained identical for both the pre- and posttested. The pretesting occurred one week prior to the beginning of the resistance program. Once the six week training program and supplementation was complete, posttesting began the following week.

Supplementation Distribution

This was a double-blind study. Neither the subjects nor the researchers were aware of which subjects were receiving the supplement or the placebo. The subjects received a new form of creatine produced by Experimental and Applied Sciences located in Pacific Grove, CA. The new form is named Phosphagens, which look and

taste very similar to sour patch kids. Phosphagens are tablets that contain approximately 0.85-g of creatine monohydrate per tablet. The supplement was dispensed in packages which contained six tablets (approximately 5-g per package). The placebo was identical in size, shape, and taste, since creatine monohydrate is tasteless.

The subjects reported to the researcher's office to receive their weekly ration of supplement or placebo. This occurred the Friday prior to the start of the 6 week training period and continued every Friday thereafter until the completion of the training period. The researcher was unaware of which group was receiving the creatine, only that one group was group A and the other was group B. For the first week of the study, each experimental subject consumed 20-g/day. This was termed the loading phase. Once this was complete, each subject received 5-g per day for the duration of the study. This was termed the maintenance phase. During the loading phase, subjects were encouraged to space out ingestion of the packages throughout the day. Ingest one package with breakfast, one with lunch, one prior to training session, and the final one with dinner. During the maintenance phase, subjects were encouraged to ingest the contents of the package at the same time every day. It could have been anytime. In the morning with breakfast, prior to training session, or with dinner. It did not matter as long as it was at the same time every day.

Resistance Training Protocol

Upon the completion of the pretesting procedures, subjects began the resistance training program which coincided with the supplementation loading phase. A 4 day split routine was utilized with a heavy, light, light, heavy pattern. Wednesday was a recovery day and the subjects were strongly encouraged to restrain from any form of resistance training on this day. The periodization model was the basis of the resistance program. The main focus of the study was muscular strength development, so the program was designed to achieve optimal strength. Week one began with fairly moderate-intensity (65-75% of 1 RM) and moderate-volume (8-12 repetitions). The program quickly progressed toward a high-intensity, low-volume prescription. Weeks 4 through 6 were exclusively high-intensity (90-105% of 1 RM) and low-volume (3-1 repetitions). Posttesting immediately followed the completion of the resistance program.

Statistical Analyses

Standard descriptive statistics (mean and standard deviation) were used to quantify the subjects' demographic data and to summarize the responses of each condition. Differences between conditions (creatine versus placebo group and pre- versus posttests) were analyzed with a 2-way ANOVA with repeated measures. If a significant F-ratio was obtained, a Tukey's post-hoc test was used to detect pairwise differences. Alpha was set at the .05 level to determine statistical significance for all analyses.

RESULTS

Thirty subjects began the study, 15 in each group. Twenty-seven subjects were able to finish the study. Two subjects dropped out because of physical limitations and the other had a family situation which forced him to leave campus for a week.

The mean age of the subjects in the placebo group was 20.1 ± 1.09 years and for the creatine group, it was 20.8 ± 2.24 years. There were no significant differences ($p > .05$) between groups for bench press strength, squat strength, total body weight, body composition (% fat), lean body weight, and fat weight at the beginning of the study. Both groups showed significant increases ($p < .05$) in the bench press and the squat strength from pre- to posttest. However, there were no significant differences ($p > .05$) when comparing the changes between groups for either lift. Total body weight and lean body weight increased significantly ($p < .05$) from pre- to posttest in the creatine group only. However, there was no significant interaction between the two groups. Results for both variables did approach significance ($p = .088$ for total body weight and $p = .061$ for lean body weight). Body composition (% fat) and fat weight resulted in no significant improvements ($p > .05$) from pre- to posttest in either group. The mean data of the study are presented in Table 1.

Table 1. Results of the strength and body composition testing for the placebo (n = 14) and creatine (n = 13) groups.

	Pre	Post	Change
Bench Press (lb)			
Placebo	232.5 \pm 41.6	255.4 \pm 41.5 *	+ 22.9
Creatine	231.5 \pm 34.1	261.5 \pm 35.4 *	+ 30.0
Squat (lb)			
Placebo	322.5 \pm 39.7	382.1 \pm 54.0 *	+ 59.6
Creatine	280.4 \pm 42.3	326.5 \pm 48.1 *	+ 46.2
Total Body Wt. (lb)			
Placebo	176.4 \pm 19.1	179.0 \pm 18.5	+ 2.6
Creatine	172.8 \pm 17.1	178.2 \pm 18.1 *	+ 5.4
% Fat			
Placebo	14.7 \pm 6.0	14.8 \pm 6.1	+ 0.1
Creatine	13.8 \pm 3.5	13.6 \pm 4.0	- 0.2
Lean Body Wt. (lb)			
Placebo	149.8 \pm 11.0	151.9 \pm 11.9	+ 2.1
Creatine	148.8 \pm 14.7	153.5 \pm 13.9 *	+ 4.8
Fat Weight (lb)			
Placebo	26.6 \pm 12.8	27.1 \pm 12.9	+ 0.5
Creatine	24.0 \pm 7.0	24.6 \pm 8.6	+ 0.6

NOTE: All values represent the mean \pm SD

* = significantly different than pretest (p < .05)

DISCUSSION

The purpose of this study was to determine and validate the effectiveness of creatine monohydrate supplementation to improve muscular strength and body composition. The purpose of this study was also to establish research on these components of the anaerobic athlete. As stated earlier, much research has been done on anaerobic power and capacity. However, very little research has focused on the effects of creatine monohydrate supplementation on muscular strength and body composition. The results demonstrated a significant increase in the bench press and squat strength from pre- to posttesting in both groups. The placebo group increased 22.9 pounds in the bench press and 59.6 pounds in the squat following the 6 week training program. The creatine group increased 30.0 pounds in the bench press and 46.2 pounds in the squat in 6 weeks. Thus, creatine did not appear to be effective in improving muscular strength. Since both groups did improve strength to the same degree, the improvements seem to be related to the resistance training program, not the creatine supplementation. These results agree with those of Earnest et al. (4). In the Earnest et al. study, a 6% increase was noted in 1 repetition maximum bench press strength and total repetitions at 70% of 1 RM in a creatine group which took creatine for 28 days. However, when the results were corrected for body weight, no significant differences were noted because of a significant increase in body weight (4).

Total body weight and lean body weight increased significantly from pre- to posttesting in the creatine group only. For total body weight, the creatine group increased 5.4 pounds, with 4.8 pounds being lean body mass. These findings are consistent with those of Earnest et al. (4) and Volek et al.(10). These studies reported a 3.5 pound increase in total body weight in a creatine supplemented group, as well as a nonsignificant increase in calculated fat free mass (4,10). Volek et al. reported a 2.8 pound increase in total body weight in a creatine supplemented group.

Body composition (% fat) and fat weight did not change significantly from pre- to posttesting in either group in the present study. These findings also agree with Earnest et al. and Volek et al. (4,10). Earnest et al. (4) reported no change in body fat as determined by skinfold thickness. Volek et al. (10) reported no increase in skinfold thickness in either a creatine supplemented or placebo group. No negative side effects were reported by the subjects in the present study or by Earnest et al. or Volek et al. (4,10).

There may be several possible explanations for the results of this study. First, subjects may have not ever been exposed to this intense of a resistance program. The improvements in muscular strength and body composition may be a result of the new resistance training program. The creatine supplementation may not have been given a chance to show significant difference. A 4 week base training period may have been beneficial prior to the start of the training/supplementation period. This may have established a more stable starting point for all subjects. Second, the

was predetermined by Experimental and Applied Sciences (EAS). Thirdly, activities performed by the subjects outside of the study could not be controlled for (i.e., aerobic activity, diet, sleep patterns, and alcohol and drug use). Any or all of these factors could have affected the results. Fourth, a new form of creatine monohydrate, Phosphagens - EAS, was used for supplementation purposes. Since this was an experimental form of creatine monohydrate, it may not work as well as creatine monohydrate in its purest form.

Under the circumstances and based on the data collected during this study it is concluded that the creatine monohydrate supplement Phosphagens has no significant effect on muscular strength and body composition. However, since creatine has proven to be beneficial in allowing an athlete to perform longer and more bouts at high-intensities, it is conceivable that longer workouts at higher intensities will elicit development of muscle mass and greater strength gains. Researchers may need to focus on the best training regimen to capitalize on the effect of creatine on the body. Another area of question with creatine monohydrate supplementation is how long should an athlete use the supplement. Should they cycle it, two months on, one month off, with the loading phase occurring at the beginning of each phase or should the athlete load once and maintain for the duration of their athletic career? These are questions that arise as often as "does creatine work?" These are the questions that must be answered by future researchers.

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APPENDIX A
INFORMED CONSENT FORM

INFORMED CONSENT FORM

The University of Wisconsin-La Crosse
La Crosse, Wisconsin

THE EFFECT OF CREATINE MONOHYDRATE SUPPLEMENTATION ON MUSCULAR STRENGTH AND BODY COMPOSITION (Harold C. Luther II)

I give my informed consent to participate in this study to determine the effect of creatine supplementation and its effect on muscular strength and body composition. I consent to publication of the study results so long as the information is anonymous and disguised so that no identification of the individual subjects can be made. I further understand that although a record will kept of my having participated in the experiment, all experimental data collected from my participation will be identified by number only.

I, _____, have been informed of and
(Name of Subject)
completely understand the following:

1. The purpose of this study is to determine the potential benefits of creatine ingestion (Phosphagens brand manufactured by Experimental & Applied Sciences, Pacific Grove, CA) as it relates to muscular strength and body composition as suggested by previous studies. Creatine is a nutrient that is produced naturally by the body and is also routinely ingested in meat or fish.

I will be placed into one of two groups, an experimental group (who will receive the creatine supplement) or a control group (who will not receive

creatine, but will instead receive a placebo), by the researchers. I will undergo identical batteries of pre- and post-testing, each requiring approximately three hours. These will include 1-RM bench press, 1-RM squat, and hydrostatic weighing.

Both groups will undergo an identical six-week high-intensity strength training program, requiring approximately one to two hours per day, four days per week, to be completed at the UW-L Strength Center. The experimental group will be supplemented with 20 grams of creatine per day for the first five days (loading phase) and 5 grams per day every day thereafter (maintenance phase) for the remainder of the six-week training program. The control group will undergo an identical

supplementation protocol with a placebo. The study will be conducted as a double-blind design. Neither I nor the principal researchers will know into which group I have been placed. I will be required to receive my weekly ration of supplement at 021 Mitchell Hall from the principal researchers on the Friday preceding each week of the supplementation period.

2. As with any training protocol, potential risks are present. Muscle soreness, cramping, muscle strains, and muscle tears are all potential risks when participating in a resistance training program. Also, being in a strength and conditioning facility always presents potential risks. The possibility of being seriously injured through extraordinary circumstances is present (i.e., broken bones, ligament damage, disc ruptures, etc.) .

Potential risks or side effects with the creatine supplementation may range from increased body mass to increased urination. Gastrointestinal discomfort, diarrhea, increased urination, dehydration, and muscle cramping have been anecdotally reported as side effects. These are most often associated with the loading phase. However, all of these effects have been mild and short-lived, lasting no more than a few days. Also, none of these has been directly tied to creatine supplementation in published studies.

The testing procedures also involve a certain amount of inherent risk. Because the hydrostatic weighing protocol involves climbing into the weighing tank and being fully submerged underwater, slipping, falling, and drowning are potential risks.

3. Both the creatine and the placebo groups should experience increases in strength as a result of the weight training program. In addition, the results will shed light on the validity of creatine as a supplement for further increasing muscular strength and lean body mass.
4. I will be encouraged to continue all other activities as normal while remaining in good health and remembering that part of the success of the study depends upon the conditions of the pre- and posttesting sessions being as similar as possible, with the exception of the experimental treatment.
5. I will be given a number at the beginning of the study. This number will be placed on all relevant materials used to identify me throughout the study (i.e., testing results sheets, training and attendance cards, and distribution of the supplement). Only the researcher will have knowledge of my number.
6. Concerns about any aspect of this study may be referred to the principal researchers, Harold C. Luther II (785-8708) and the thesis advisor, John Porcari, Ph.D. (785-8684).

7. My participation in this study is completely voluntary. I am free to withdraw from the study at any time without penalty of any kind.

Witnessed by:

Experimental Participant Date

Principal Researcher Date

Principal Researcher Date

APPENDIX B
REVIEW OF RELATED LITERATURE

REVIEW OF RELATED LITERATURE

Introduction

Athletes are searching for ways to succeed. Competition in athletics has propelled technology to search for new advances in order to raise the limit in human performance. Resistance training programs, psychological interventions, and the use of ergogenic aids have been developed or manipulated to give an athlete the best mixture for success. Recently, the focus has shifted to ergogenic aids. Carbohydrate-loading, high fat diets, protein ingestion, and the use of caffeine, diuretics, and anabolic steroids are some of the aids that have been experimented with by athletes to enhance performance. Carbohydrate-loading has shown to be effective in the endurance athlete. The strength and power athlete has not been as fortunate. Anabolic steroid use, caffeine use, and high fat diets have shown to benefit the anaerobic athlete; however, the negative side effects outweigh the benefits. The most recent focus of an ergogenic aid is the supplementation of creatine monohydrate. This may be the anaerobic athlete's answer to a performance enhancing aid.

Previous studies have shown significant changes in anaerobic power and capacity, and high-intensity intermittent exercise through the use of creatine monohydrate (2, 4, 5, 7, 12, 13). A few studies have shown significant changes in muscular strength and body composition. Not only has creatine resulted in enhanced anaerobic performance, no negative side effects have been reported (6, 11).

Muscle Physiology

To understand how creatine monohydrate affects human muscle metabolism, structure, and function, muscle physiology must be discussed. Each skeletal muscle is an organ which contains muscle tissue, connective tissue, nerves, and blood vessels. Fibrous connective tissue, or epimysium, covers the body's more than 430 skeletal muscles. Myofibrils contain the apparatus that contracts the muscle cell, which consists primarily of two types of myofilaments: myosin (thick) and actin (thin). Myosin and actin filaments are organized longitudinally in the smallest contractile unit of skeletal muscle, the sarcomere. The sarcomere is the functional unit of the muscle (1).

Sliding-Filament Mechanism of Muscle Contraction

In its simplest form, the sliding-filament mechanism states that actin filaments at each end of the sarcomere slide inward on myosin filaments, pulling the Z-lines toward the center of the sarcomere and thus shortening the muscle fiber. The cross bridges on the thick filament (myosin) pull the thin filament (actin). As actin filaments slide over myosin filaments, the H-zone and I-band shrink (9).

The Energy Source for Cross-Bridge Flexion

The energy for cross-bridge flexion comes from the hydrolysis (breakdown) of adenosine triphosphate (ATP) to adenosine diphosphate (ADP) and phosphate, a reaction catalyzed by the enzyme myosin ATPase. Another molecule of ATP must

replace the ADP on the myosin cross-bridge head for the head to detach from the actin site and recock. This allows the contraction process to continue (if calcium is available to bind to the troponin molecule) or relaxation to occur (if calcium is unavailable) (1).

Creatine and the Resynthesis of ATP

An endurance athlete produces energy aerobically, with the aid of oxygen. ATP is resynthesized using glycogen first and then oxygen. The endurance athlete does not need to produce great amounts of force, only minimal, but steady force. Type I muscle fibers are primarily responsible for such action. In a power athlete, large amounts of energy must be created quickly. This is termed anaerobic or without oxygen. Type II muscle fibers are the primary muscle type involved. ATP must be resynthesized through some other process. This is where creatine monohydrate comes into the play. Enough ATP is stored in the muscle for approximately 3-6 seconds of maximal contraction. The muscles also store creatine phosphate for activity. Once the ATP stores are depleted, creatine phosphate (CP) is combined with ADP to form ATP. Creatine kinase (CK) is the enzyme responsible for breaking CP into creatine and phosphate. The free phosphate is used to bond with ADP to resynthesize ATP. Creatine also accelerates the process of recovery time between explosive movements. The resynthesis process for recovery occurs in the same fashion.

Strength Training Program Design

In order to research the anaerobic component of human performance, subjects were trained anaerobically through a proper strength training program design. A program of resistance training is designed to develop strength. The basis of all gains in any type of fitness endeavor is the overload principle, which means providing a greater stress or load on the body than it is normally accustomed to handling (1).

The periodization training model has become the accepted norm in strength and conditioning for developing muscular strength and power in competitive athletes. According to Baechle (1), there are three phases in periodization: hypertrophy, strength, and power. The hypertrophy phase focuses on developing muscle mass in the athlete. The strength phase develops the new muscle mass to become stronger. In the power phase, a speed component is added along with the newly developed strength. The athlete must develop mass before becoming stronger and faster. The periodization model was originally developed to train Olympic athletes. There are three cycles that are associated with periodization. A macro-cycle typically consists of three or four meso-cycles per year. A meso-cycle consists of a hypertrophy, strength, and power phase. This typically requires 12 to 13 weeks to complete. A micro-cycle is the 3 or 4 week period designated to one of the three particular phases.

Training frequency refers to the number of training sessions completed in a given period of time. Without proper training frequency, training may be unproductive and possibly dangerous (9). The suggested frequency for a resistance

training program is at least 3 days per week and no more than 6 days per week with at least 48 hours recovery time for each specific muscle group (1).

Volume describes the total amount of weight lifted in a training session. The total number of repetitions with various loads in training session is also termed volume (9). Volume is increased during the hypertrophy phase. Gradual reductions in volume begin as intensities in the training program increase in the strength and power phases. The lowest volumes are performed in the late part of the power phase and in the competition period of training, according to Baechle (1).

Training conditioning is recognized as the most critical aspect of a resistance program. Intensity of training is often synonymous with training load (amount of weight per repetition) (9). Using a percentage of the one repetition maximum (RM) is one of the simplest methods of determining the load or intensity that an athlete should use. According to Baechle (1), intensities of at least 80% of 1RM need to be performed to facilitate maximal gains in strength. Frequency, volume, and intensity interact directly. Each component is directly related. For example, if the volume is high, then the intensity must be low. If this does not occur, the results may be injury, decreased motivation, or more often than not, decreases in strength.

Rest periods between sets of exercise are critical in the success of any training program. Training for absolute strength requires significantly longer rest periods between sets of exercise than training muscle hypertrophy or local muscle endurance (9). According to Baechle (1), a 48 hour recovery period is suggested between

training sessions of a particular muscle group. This allows for the muscle to rebuild the protein that was broken down in the previous training session. If a muscle is not allowed to rebuild and grow, overtraining may occur and possibly injury.

Effects of Creatine Monohydrate Supplementation on Anaerobic Performance,

Muscle Strength, and Body Composition

Creatine has been a known nutritional supplement since the early 1800's, but only recently has it been researched as to how it affects anaerobic components. As early as 1923, creatine was shown to benefit anaerobic exercise performance (3). The ergogenic effect of creatine ingestion is most likely a result of increased preexercise availability of creatine and phosphocreatine and enhanced phosphocreatine resynthesis during recovery from exercise (13). Therefore, athletes involved in activities that are predominantly anaerobic in nature (high-intensity, short duration) are most likely to benefit from creatine supplementation. According to Kreider (8), the body can only store so much creatine. Once this limit is reached, excess creatine is removed from the body through urination. An athlete that consumes high amounts of creatine in their diet (i.e., red meats, poultry, and fish) may only experience minimal gains in creatine stores. On the other hand, if an athlete does not consume high amounts of creatine, creatine supplementation may elicit greater improvements in muscular strength. If increased phosphocreatine levels are maintained for an extended time, individuals in training may benefit from being able to train at higher intensities for longer periods of time before fatigue sets in (13). More intense training

should promote a better training response, assuming recovery is adequate to meet the increased demands placed on the individual.

According to the literature, the recommended dosage for the loading phase is 20-25 g/day for five days. The typical guideline for loading is if a subject weighs less than 225 pounds, 20 g/day will be sufficient. If the Training subject weighs more than 225 pounds, the dosage needs to be adjusted up to 25 g/day to account for more muscle mass. A few studies have experimented with a loading phase as long as 10 days with no maintenance phase. Others have used no loading phase and supplemented throughout the study using maintenance doses.

Muscle creatine appears to be “trapped” in the muscle and may stay elevated for an extended time (> 1 month) once the tissue levels have been elevated by prior creatine monohydrate supplementation (13). Recent evidence suggests that once the muscle creatine stores have been elevated by creatine supplementation, the dosage may be reduced to 3-5 g/day to maintain elevated creatine stores in the muscle. The recommended dosage for the maintenance phase is 5-10 g/day for the duration of the study. The maintenance phase begins the day after the loading phase is complete. The same guidelines apply with the maintenance phase. If a subject weighs less than 225 pounds, 5 g/day will be sufficient. If the subject weighs 225 pounds or over, the recommended dosage is 10 g/day.

Earlier studies began to research the effect of creatine supplementation on dynamic high-intensity exercise. Two high-intensity exercise protocols were

performed before and after the administration of either creatine or a placebo, and performance characteristics and selected physiological response were studied by Balsom et al. (2). Sixteen healthy male subjects were randomly placed in one of two groups, an experimental group and a control group. Body mass and anaerobic performance were the measured parameters. Subjects were given 20 g of supplement per day for 5 days and then 5 g/day every day thereafter following pretesting. In the creatine group, body mass increased 1.6 kg before versus after the administration period, with no significant changes found in the placebo group. To study the exercise performance component, a 6-s sprint on a stationary bike at 140 revolutions per minute was performed by both groups before and after the administration of creatine or placebo. The exercise period was divided into three intervals: 0-2-s, 2-4-s, and 4-6-s. For the first interval, all subjects were able to maintain the target speed over the 10 trials before and after administration. Before administration, there were no significant differences in mean pedal speed between the two groups along trials for either the 2-4-s or 4-6-s interval. After administration, there was a tendency over the last few bouts of the 2-4-s interval for the creatine group to maintain a higher pedal frequency. During the 4-6-s interval, the difference between groups became significant. It was concluded that increasing total muscle creatine can delay the onset of fatigue during repeated bouts of high-intensity exercise.

A study by Greenhaff et al. (7) researched the influence of creatine supplementation on muscle torque during repeated bouts of maximal voluntary

contraction. Twelve subjects underwent five bouts of 30 maximal voluntary isokinetic contractions, interspersed with 1 minute recovery periods, before and after 5 days of placebo or creatine supplementation. Muscle torque production was measured during and after exercise on each treatment. No differences were observed when comparing peak muscle torque production during exercise before and after placebo ingestion. After creatine ingestion, peak muscle torque production was greater in all subjects during the final 10 contractions of exercise bout 1, throughout the whole of exercise bout 2, bout 3, and bout 4, and during contractions 11-20 of the final exercise bout, when compared with the corresponding measurements made before creatine ingestion. The major finding of this experiment is that a group of six subjects were all able to sustain peak isokinetic torque production at a higher level during repeated bouts of maximal voluntary contractions, following a regimen of 20-g per day for 5 days.

A recent study by Prevost et al. (10) investigated the impact of creatine supplementation on high-intensity, intermittent work. Eighteen subjects each performed two sets of four different work bouts to exhaustion. For 5 days prior to the first set of work bouts, all subjects received a placebo (5-g per day). For the second set of work bouts, 9 subjects again received the placebo, while the other 9 subjects received creatine supplementation (approximately 20-g/day for five days and 2.25-g/day during testing). The four bouts in each set consisted of cycling to exhaustion at 150% peak oxygen uptake either nonstop (A), intermittently for either 60-s work/120-

s rest periods (B), 20 s work/40-s rest (C), or 10-s work/20-s rest (D). Creatine supplementation significantly increased the total work time of all bouts. Protocol D showed the greatest increase (>100%); C increased 61.9%; B increased 61.0%; and A increased 23.5%. These results demonstrate that creatine supplementation significantly extends one's capacity to maintain a specific level of high-intensity intermittent exercise.

The following studies focused on the effects of creatine supplementation on muscular strength and body composition. A double-blind experiment was administered by Earnest et al. (5) to research the effect of creatine monohydrate ingestion on the anaerobic power indices of muscular strength and body composition in eight subjects. A 28 day creatine supplementation period followed pretesting. Each subject received 20-g of creatine monohydrate or placebo per day for 5 days and 5-g of supplement per day everyday thereafter. Both groups performed the Wingate test to determine maximum anaerobic power and capacity. The creatine group produced significantly higher power outputs during all posttest trials. No changes were noted in the placebo group. Bench press 1RM increased 6% in the creatine group; however when this increase was corrected for change in body weight no differences were noted because of a significant increase in body weight within the creatine group. Total lifting volume was significantly higher within the creatine group, when expressed in either absolute or relative terms. Body composition data indicated a significant increase in body weight (1.6 kg), as well as a nonsignificant increase in calculated fat

free mass for the creatine group. No changes in body weight or fat free mass were noted for the placebo group. The observed higher workouts in the creatine group were consistent with increases in intramuscular phosphocreatine stores, increased ATP cycling, and an increased rate of phosphocreatine resynthesis during recovery periods, as noted in previous studies.

A study by Volek et al. (14) investigated the influence of oral creatine monohydrate supplementation on hormonal responses to high-intensity resistance exercise in 13 healthy, normally active men. Subjects were randomly assigned in double-blind fashion to either a creatine or placebo group. Both groups performed bench press and jump squat exercise protocols before and after ingesting either 25-g of creatine monohydrate or placebo per day for 7 days. Although the main focus of this study was on hormonal changes, creatine ingestion did result in a significant increase in body mass, with no change in skinfold thickness. The 1.3 kg increase in body mass in the creatine group agrees with previous studies involving creatine supplementation. This investigation was also the first to demonstrate that following creatine supplementation, total repetitions performed during five sets of bench press as well as peak power output during five sets of jump squats were enhanced.

Volek and Kraemer (13) published a review article in 1996 discussing creatine supplementation and its effects on human muscular performance and body composition. Creatine monohydrate supplementation appears to result in an increased ability to maintain power output during high-intensity exercise and increase the rate

of phosphocreatine resynthesis during the recovery phase of intermittent high-intensity exercise. Subjects supplemented with creatine monohydrate demonstrate a reduction in the accumulation of plasma lactate, ammonia, and hypoxanthine, indicating an alteration in energy metabolism and an attenuation of ATP degradation. Thus, higher concentrations of creatine seem to enhance the muscle's ability to sustain the high ATP turnover rates encountered during strenuous exercise. Another potential benefit is an increase in body mass which results from ingestion of creatine monohydrate; however, the composition of the weight gain remains undetermined.

Summary

The results of creatine studies that used intermittent high-intensity protocols with relatively short rest periods generally indicate improvements in performance, especially sprint cycling and weightlifting protocols. Few studies have tested the effects of creatine supplementation on muscular strength and body composition directly. There have been indirect implications, but nothing stable. Few studies have tested the effects of creatine supplementation on specific athletes. For example, the effects of creatine monohydrate supplementation on athletes involved in specific sports that require short bursts of power, like soccer, tennis, or basketball, remain unknown.

Since many of the findings presented above have questionable validity regarding muscular strength and body composition, it was the purpose of this study to establish the validity of creatine monohydrate as an effective nutritional supplement.

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