

Creatine Use in Sports

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Context: The use of creatine as a dietary supplement has become increasingly popular over the past several decades. Despite the popularity of creatine, questions remain with regard to dosing, effects on sports performance, and safety.

Evidence Acquisition: PubMed was searched for articles published between 1980 and January 2017 using the terms *creatine*, *creatine supplementation*, *sports performance*, and *dietary supplements*. An additional Google search was performed to capture National Collegiate Athletic Association–specific creatine usage data and US dietary supplement and creatine sales.

Study Design: Clinical review.

Level of Evidence: Level 4.

Results: Short-term use of creatine is considered safe and without significant adverse effects, although caution should be advised as the number of long-term studies is limited. Suggested dosing is variable, with many different regimens showing benefits. The safety of creatine supplementation has not been studied in children and adolescents. Currently, the scientific literature best supports creatine supplementation for increased performance in short-duration, maximal-intensity resistance training.

Conclusion: While creatine appears to be safe and effective for particular settings, whether creatine supplementation leads to improved performance on the field of play remains unknown.

Keywords: creatine; sports; performance; dietary supplements; ergogenic aids

In the United States, sales of dietary supplements exceeded \$38.8 billion in 2015, with sports supplements accounting for 14% of total sales.³² In a recent systematic review and meta-analysis, dietary supplements were more commonly used by athletes compared with the general population and by elite versus nonelite athletes.²³

Creatine is a nitrogenous organic compound found in muscle and is available in the diet through consumption of milk, red and white meat, fish, and mollusks, with meat and fish serving as the main supply. A typical carnivorous diet supplies 1 to 2 g of creatine per day, although cooking time, type of meat, and muscle site all influence creatine values after ingestion.²⁰ An average 70-kg young man has a creatine pool between 120 and 140 g, varying by muscle fiber type and muscle bulk.¹⁰

Creatine supplementation gained mainstream popularity after the 1992 Olympic Games in Barcelona.⁹ Creatine was first discovered in 1832 and can be traced back to the mid-1800s.³⁹

Creatine is now widely used among recreational, collegiate, and professional athletes.^{15,39} Creatine is one of the most popular sports dietary supplements on the market, with more than \$400 million in annual sales.³¹

Creatine as a dietary supplement is a tasteless, crystalline powder that readily dissolves in liquids and is marketed as creatine monohydrate or as a combination with phosphorous.³⁷ The majority of creatine (95%) is stored in skeletal muscle (fast twitch, type II): two-thirds in a phosphorylated form and one-third as free creatine. Creatine serves as an energy substrate for the contraction of skeletal muscle. The intention of creatine supplementation is to increase resting phosphocreatine levels in muscles, as well as free creatine, with the goal of postponing fatigue, even briefly, for sports-enhancing results.

Creatine use is widespread but difficult to quantify as the data to date are limited to self-report surveys (limited by response error).²³ The National Collegiate Athletic Association (NCAA)

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The authors report no potential conflicts of interest in the development and publication of this article.

DOI: 10.1177/1941738117737248

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National Study of Substance Use Habits of College Student Athletes survey reported that 14% of athletes used creatine in the 12 months prior to the survey, and users were more commonly men than women.³⁵ The National Health Interview survey found creatine use among children and adolescents to be 34.1%, with the purpose of enhancing sports performance.¹³ In the military, creatine is highly popular, with an average use of 27%.¹⁸

MECHANISM OF ACTION

Creatine is produced endogenously in the liver, kidneys, and to a lesser degree, the pancreas, at 1 gram per day.¹⁰ The remainder of available creatine is consumed through the diet, synthesized from essential (arginine, methionine) and nonessential (glycine) amino acids.¹⁸ Creatine is tightly regulated, with a balance between synthesis by liver enzymes responsible for the final step in creatine synthesis (methylation) and creatinine (anhydro products) levels in the blood stream, which regulate excretion rates.¹⁸ Cells with high energy requirements use creatine in the form of phosphocreatine.¹⁸ Phosphocreatine serves as a source of phosphate to produce adenosine triphosphate (ATP) from adenosine diphosphate (ADP). Skeletal muscle cells store enough ATP and phosphocreatine for approximately 10 seconds of high-intensity activity; short-term creatine supplementation leads to a total creatine increase of 10% to 30%, with phosphocreatine stores increasing by 10% to 40%.^{24,31}

DIRECTIONS FOR USE

Creatine Dosing

The recommendations regarding dosing of creatine supplementation as an ergogenic aid are varied.¹⁰ While many studies have reported promising results with building lean muscle mass or improvements in “quick burst” athletic performance, there are no firm guidelines regarding a supplementation regimen. A recent meta-analysis of creatine doses ranging from 0.07 g per kg body weight per day to 5 g/d revealed favorable outcomes for creatine with resistance training for increasing lean muscle mass.¹² When comparing studies, it does not appear that these outcomes were dose-dependent. Hall and Trojian¹⁶ advise 0.03 g per kg per day as a maintenance dose, for 4 to 6 weeks on average, based on multiple reviewed studies.¹⁶ However, maintenance use of creatine has ranged from 28 days to 10 weeks. Most commercially available creatine supplements are packaged to contain between 4 and 5 grams of creatine per dose. While some of these supplements recommend once-daily dosing, many appear intentionally vague regarding recommended frequency or duration of dosing. These products are not regulated by the US Food and Drug Administration, and thus, individual products often contain unreliable or variable quantities of the desired supplement and may contain unintended ingredients such as banned substances.²²

A loading dose of creatine is often used prior to implementation of a daily maintenance dose. Some studies have indicated that creatine stores can be increased without a loading

dose, albeit over longer periods of time.⁶ A commonly accepted loading dose regimen is 20 to 25 grams per day, divided 4 times daily for 5 to 7 days,¹⁰ with variability between recommended loading doses.¹⁶ The International Society of Sports Nutrition supports a loading dose of approximately 0.3 g per kg per day for at least 3 days.⁶ However, there is no consistency in loading dose recommendations in strength, frequency, or duration.¹²

EFFECTS ON EXERCISE AND PERFORMANCE

Harris et al¹⁷ were the first to document increased muscle creatine concentrations of 20% with creatine supplementation in the form of creatine monohydrate. Creatine supplementation increases lean body mass as well as strength, power, and efficacy in short-duration, high-intensity exercises.¹⁵ These ergogenic effects have been studied extensively in the weight room and laboratory, with limited studies in active game play scenarios. A meta-analysis from 2003 including 100 studies demonstrated significant improvements in laboratory-based exercise but did not show improvements in sports-specific activities after short-term creatine supplementation.⁵ Other studies have shown no improvement with sports-specific activities related to simulated soccer participation,^{8,46} simulated wrestling,¹ tennis,³³ or swimming.³⁸

One of the ergogenic effects of creatine supplementation is increased body mass. A meta-analysis showed that approximately 64% of studies measuring body mass and/or body composition noted a statistically significant increase in lean body mass due to creatine supplementation.⁵ The increases in body mass were thought to be the result of increased intracellular water related to fluid shifts due to the osmotic properties of creatine.^{1,4,36} Increased body mass has been noted in those using a creatine supplement without participation in an associated exercise program. However, taking creatine in conjunction with a resistance training program yielded greater increases in body mass.¹⁰

Studies on creatine supplementation demonstrate increases in performance and strength in short-duration, maximal-intensity exercises, as measured by 1-repetition maximum, muscular power, number of repetitions, muscular endurance, speed, and total force.^{1,4,40-44,47,48} Strength gains after 28 days between groups taking creatine alone, creatine plus resistance training, and placebo plus resistance training showed all groups significantly increased ($P < 0.01$) bench and leg press muscular strength, with the creatine plus resistance training group improving significantly more than the group taking creatine alone.² In meta-analyses of creatine supplementation on upper and lower extremity performance, increased strength performance related to creatine supplementation was noted for both the upper and lower extremity.^{27,28} There was improved performance with creatine supplementation in conjunction with a resistance training program, especially evident in those with no previous training history (defined as exercising less than 3 h/wk).²⁸ Changes in performance were independent of age, sex,

supplement dosage, and supplement duration. The meta-analysis focusing on upper extremity response to supplementation displayed the most significant strength increases, mainly at the pectoralis muscles (major and minor), with performances in bench press increasing by approximately 5.3% with creatine supplementation.²⁶ Other studies have demonstrated similar improvements in bench-press performance.^{7,21,34,48}

Most team sports require a combination of aerobic and anaerobic activities, which necessitates a combination of strength and endurance. Peripheral fatigue as a result of aerobic training may potentially decrease strength and performance. Creatine supplementation may prevent loss of strength as a result of aerobic activity when combined with anaerobic activities in recreational athletes.¹¹

Results have been inconsistent overall with regard to an individual athlete's response to creatine supplementation.²⁹ This may in fact be due to preloading of creatine. Athletes with a higher baseline level of creatine before supplementation are less likely to derive benefit than an athlete with a low baseline level of creatine. This likely explains why some athletes appear to be "responders" to creatine supplementation while others are "nonresponders."²⁹

Currently, the scientific literature best supports creatine supplementation for increased performance in short-duration, maximal-intensity resistance training with a noted effect on lean body mass. Whether these effects of creatine supplementation lead to improved performance on the field of play remains unknown.

SAFETY CONCERNS

Short-term use of creatine is considered safe and without significant adverse effects, although caution should be advised as the number of long-term studies is limited.⁹ The International Society of Sports Nutrition notes that "there is no scientific evidence that the short- or long-term use of creatine monohydrate has any detrimental effects on otherwise healthy individuals."⁶ They go on to say that "supplementation in young athletes is acceptable and may provide a nutritional alternative to potentially dangerous anabolic drugs."

Many theories regarding adverse effects of creatine have been proposed, including potential for renal damage, hepatic injury, and difficulty maintaining hydration.²² There have been theoretical concerns regarding potential effects of creatine supplementation on renal function. Multiple studies have examined serum creatinine levels, while none has indicated any evidence of increased serum creatinine in young, healthy individuals.^{22,25} There have been isolated case reports of athletes sustaining hepatic injury with creatine use.³ However, each of these cases involved excessive or inappropriate creatine use or multiple ergogenic aids and supplements.³ These adverse reactions have not been identified in larger, healthy populations taking creatine in appropriate therapeutic doses.²⁵

Creatine is known to cause mild water retention and decreased urinary volume due to its osmotic effect. This may result in temporary weight gain, particularly during the loading phase. Because of the increased intracellular water volume, there is an increased risk of compartment syndrome, muscle cramps, dehydration, or heat illness.²² However, none of these potential adverse reactions have been supported.^{14,19,30,45} The safety of creatine supplementation is unknown in children and adolescents.

TESTING

Creatine is available over the counter and in various forms. It is not screened for or banned by the World Anti-Doping Agency (WADA), the International Olympic Committee (IOC), or the NCAA. However, these products are not regulated by the US Food and Drug Administration and may contain contaminants or variable quantities of the desired supplement.

CONCLUSION

Short-term use of creatine is considered safe and without significant adverse effects, although caution should be advised as the number of long-term studies is limited. The safety of creatine supplementation has not been studied in children and adolescents. Currently, the scientific literature supports creatine supplementation for increased performance in short-duration, maximal-intensity resistance training. Whether these effects of creatine supplementation lead to improved performance on the field of play remains unknown.

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