AIS SPORTS SUPPLEMENT FRAMEWORK
CREATINE MONOHYDRATE

What is it?

> Creatine is a non-essential nutrient that is endogenously synthesized (about 1 g/d) and also ingested through the diet (about 1 g/d). Creatine is heavily concentrated in animal muscle (e.g. meat and fish), which is the primary dietary source for omnivores. Muscle and blood creatine levels are reduced in vegetarians who consume little in the diet.[1]

> Most creatine is stored in skeletal muscle where it exists in free (i.e. creatine) and phosphorylated (i.e. phosphorylcreatine) forms. Creatine and phosphorylcreatine provide energy to support brief, intense exercise. Although the rate of energy production from muscle creatine is very high, storage capacity is very limited. There is enough creatine in skeletal muscle to support about 8 to 10 seconds of maximal exercise. Creatine monohydrate is a dietary supplement that, when ingested in accordance with current guidelines, can increase skeletal muscle creatine and phosphorylcreatine and subsequently improve high-intensity exercise performance.[1]

> A small amount of creatine is present in the brain, where it is also used to support energy production. Brain creatine can be increased with creatine monohydrate supplementation, albeit to a smaller amount than the increase seen in skeletal muscle.[2] The benefits of creatine supplementation on brain health include improved cognitive processing and potentially reduced damage and enhanced recovery from mild traumatic brain injury (mTBI/concussion).[3]

What does it look like?

> Creatine monohydrate is a white powder that can be ingested after combining it with liquid (e.g. a post-exercise protein-carbohydrate recovery drink) or food (e.g. Greek yogurt). Creatine supplements should be ingested immediately following mixing, as in liquid form, creatine quickly degrades to creatinine.

> Creatine monohydrate is very well absorbed (>99%)[4] whereas alternate creatine supplements (e.g. creatine ethyl ester) that advertise "better absorption" do not have data to back such claims. Multiple creatine dietary supplements are available for purchase, but about 99% of the safety and efficacy data are available on creatine monohydrate powder. There is no scientific reason to take a creatine supplement other than creatine monohydrate.

How and when do I use it?

> Professor Roger Harris first demonstrated that oral ingestion of creatine monohydrate can increase muscle creatine and phosphorylcreatine. After many years of study, multiple research teams confirm that muscle creatine can be increased by ingesting about 5 grams of creatine monohydrate, 4 times per day, for about 5 days (i.e. "creatine loading").[5] Suggested dosing based on body mass is about 0.3 g of creatine/kg body mass per day, for 5 days, typically in 3-4 divided doses (i.e. with meals), followed by a maintenance dose of 0.03g/ kg body mass once a day thereafter.

> Subsequently, Professor Eric Hultman showed that increased muscle creatine could be maintained after creatine loading with ingestion of a maintenance dosage of about 3 to 5 g/d).[6] Alternatively, one could bypass the loading phase, simply ingest a maintenance dose (3 to 5 g/d), and increase muscle creatine to saturation levels over about 4 weeks.[6]

> Muscle creatine uptake is insulin mediated, so a larger increase in muscle creatine in response to supplementation could be obtained with co-ingestion of a meal that generates an acute increase in blood insulin levels. Early studies used large amounts of simple sugars to accomplish this (i.e. >90 g of sugar + 5 g creatine four times/d), but subsequent studies confirm the same effect can be accomplished by ingesting creatine following a meal that includes both protein (50 g) and carbohydrate (50 g) rich foods.

> Muscle creatine uptake is similarly increased when supplementation is combined with exercise which has insulin like effects. Although there are not many data to demonstrate that post-exercise creatine ingestion is more effective than pre-exercise ingestion, ingestion of creatine supplements following exercise and with the post-exercise meal is prudent advice and may help athletes establish a habit of proper post-exercise nutritional intake.

> Creatine loading is analogous to carbohydrate loading. Physical activities, such as endurance exercise, that are limited by carbohydrate availability and metabolism may benefit from carbohydrate loading (i.e. several days of a high-carbohydrate diet). Physical activities, such as sprinting, that are limited by creatine availability and metabolism may benefit from creatine loading/supplementation.

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- Individuals with the lowest muscle creatine (e.g. vegetarians) have the largest potential for increase in response to supplementation. Muscle creatine levels appear to be relatively unaffected by training style or intensity (i.e. sprinters do not necessarily have high muscle creatine and sprint training does not increase muscle creatine). In response to increased (e.g. supplementation) or decreased (e.g. changing to a meat free diet) dietary creatine intake, muscle creatine quickly increases or decreases, respectively.
- It is consistently found that creatine supplementation combined with resistance exercise improves resistance training outcomes, such as muscle strength, endurance, and muscle hypertrophy. This points to creatine supplementation being an effective training aid to augment strength and conditioning programs. See Table 1.
- Creatine supplementation improves the performance of brief (usually <30 sec), high-intensity exercise, especially when there are repeated bouts. These are common characteristics to many team sports, indicating that creatine supplementation can improve sports performance across a wide range of sports and activities. Maximal exercise performance is also enhanced when sprints are included during and/or at the end of endurance exercise events. See Table 1.
- There is some indication that creatine supplementation can improve recovery from periods of disuse atrophy, such as when recovering from an injury. Extremely low levels of physical activity, such as during immobilization, result in decreased muscle creatine, strength, endurance, and mass, among many other adverse changes, while creatine supplementation attenuates or reverses these decrements. See Table 1.
- Creatine supplementation has multiple direct effects on muscle (e.g. increased glycogen, phosphorylcreatine resynthesis, growth factor expression, satellite cell number, cellular hydration, etc.) which could indirectly benefit athletic performance, adaptation to exercise training, or muscular performance in a number of different patient populations.[7] See Table 1.

Table 1: Known effects of creatine monohydrate supplementation

Exercise/Performance Type	Exercise Intensity/ Duration	Benefit	Relevant Review Citation
High-intensity laboratory exercise tests	Maximal; <30 sec	Increased peak/mean power, decreased fatigue, especially over repeated bouts	1
High-intensity field exercise tests	Maximal; <30 sec	Increased speed/decreased time to complete a fixed distance	1
Swimming	Various	Increased power/decreased time to complete a fixed distance, improved performance over repeated sprint intervals likely but less likely in single sprints	8
Resistance exercise	Intermittent	Spontaneous increase in total lifting volume, increased number of repetitions at a given weight, increased strength, increased lean body mass	9, 10
Sprinting during or following endurance exercise	Maximal; <30 sec	Increased power output and speed; decreased fatigue, and time to complete a fixed distance	1
Rehabilitation from laboratory simulations of extreme inactivity	N/A	Better maintenance of muscle mass, strength, and endurance, maintenance of or increase in muscle creatine and GLUT4, increased muscle glycogen, and increased growth factor expression	11
Brain health (cognitive processing and mTBI/ concussion)	N/A	Improves cognitive processing, especially when there are brain energy deficits induced by acute (e.g. sleep deprivation, exercise) or chronic (e.g. depression, aging, mTBI) stressors. Aids in cellular energy crisis caused by mTBI and may decrease other features of mTBI, such as membrane disruption, calcium influx, nerve damage, mitochondrial dysfunction, oxidative stress, and inflammation. May improve other aspects of mTBI such as behaviour, headaches, dizziness, and fatigue	2, 3

Table adapted from previous research.[12]

Are there any concerns or considerations?

There is no evidence of systematic serious adverse effects related to creatine monohydrate supplementation. Speculation and anecdotes about muscle, renal, and thermoregulatory dysfunction are not supported with research or post-marketing surveillance.[1, 13] However, there are some implications of creatine supplementation that warrant discussion, including acute weight gain and gastrointestinal tract distress.

Rapid weight gain

> As carbohydrate ingestion and increased muscle glycogen is associated with an acute increase in body mass secondary to increased body water, increased creatine ingestion and muscle creatine is also associated with weight gain/increased body water. However, with creatine supplements, this increase in body mass is maintained as long as muscle creatine remains elevated. Following cessation of creatine supplementation, muscle creatine levels, and subsequently body mass, decrease slowly to normal over 4 to 6 weeks' time. Although this may only be a maximum of 1 or 2 kg, this could be problematic for athletes attempting to "make weight".

> Creatine supplementation offers a metabolic advantage but could present a biomechanical disadvantage for some athletes. In theory, body weight supported sports (e.g. running) could be negatively impacted by creatine supplementation. It appears these concerns are unfounded, as studies have showed improved running and swimming performance, but weight gain in some sports such as pole vaulting, in theory, could present a challenge.

Gastrointestinal tract distress

> Some people may experience mild, temporary gastrointestinal (GI) upset during supplementation, although this is anecdotal, and not widely reported in the literature.

> Avoiding the loading phase in favour of the lower-dose, longer-duration supplementation protocol, ingesting creatine with meals, not ingesting creatine at the same time as high-fibre foods or supplements that are known to increase GI disturbances (e.g. sodium bicarbonate) are all sensible decisions to help avoid GI upset.

> As with any dietary supplement, experimentation should be conducted in the off-season.

Where can I find more information?

Sports Dietitians Australia

www.sportsdietitians.com.au/factsheets/supplements/creatine-athletes

Gatorade Sports Science Institute

www.gssiweb.org/sports-science-exchange/article/the-safety-and-efficacy-of-creatine-monohydrate-supplementation-what-we-have-learned-from-the-past-25-years-of-research

Supplement safety information and batch tested product list

www.sportintegrity.gov.au/what-we-do/anti-doping/supplements-sport

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The Australian Institute of Sport (AIS) Supplement Framework is an initiative of the Australian High Performance Sport System. The AIS acknowledges the support of members of the National Institute Network (NIN) and National Sporting Organisations (NSO) and their staff in delivering content expertise. This information is intended to help athletes, coaches and scientists make evidence-based decisions about the use of supplements and sports foods. Before engaging in supplement use, we recommend that each individual refer to the specific supplement policies of their sporting organisation, sports institute or parent body, and seek appropriate professional advice from an accredited sports dietitian (**www.sportsdietitians.com.au**).

Athletes should be aware that the use of supplements may have doping implications. Athletes are reminded that they are responsible for all substances that enter their body under the 'strict liability' rules of the World Anti-Doping Code. Some supplements are riskier than others. The Sport Integrity Australia (SIA) app is a useful resource to help mitigate the risk of inadvertent doping by helping to identify supplements that have been batch-tested. The SIA App provides a list of more than 11,000 batch-tested products. We recommend that all athletes consult the educational resources of SIA regarding the risks associated with supplements and sports foods.. While batch-tested products have the lowest risk of a product containing prohibited substances, they cannot offer you a guarantee that they are not contaminated (**www.sportintegrity.gov.au/what-we-do/supplements-sport**).

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