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Comprehensive Effects of Creatine Supplementation on Physical Performance, Recovery, and Health Markers Across Diverse Populations

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Abstract

Background:
Creatine supplementation is well-established for its ergogenic benefits, enhancing physical strength, endurance, recovery, and fatigue management across diverse populations. Research highlights its role in mitigating exercise-induced muscle damage and improving health markers, including oxidative stress, hydration, and body composition. This review synthesizes current evidence on creatine's comprehensive effects across varied demographics and activity contexts.

Methods:
This review examined creatine's effects on performance, recovery, and health markers across athletes, older adults, postmenopausal women, and long COVID patients, analyzing strength, endurance, fatigue, body composition, and biochemical metrics with demographic subgroup analyses.

Results:
Creatine supplementation improved muscle strength, endurance, and fatigue resistance, especially when combined with resistance training. Benefits included enhanced sprint and jump performance, recovery from muscle damage, and better fatigue management. It also increased lean mass and hydration, reduced oxidative stress, supported bone health, and improved quality of life in clinical populations.

Conclusion:
Creatine supplementation offers broad benefits for performance, recovery, and health, particularly in athletes, older adults, and clinical populations. Its synergy with resistance training and other supplements underscores its versatility. Future studies should focus on personalized protocols to maximize effectiveness and address individual variability.

Keywords:
Creatine supplementation, physical performance, muscle recovery, body composition, oxidative stress, health markers, diverse populations.

Introduction

Creatine supplementation has garnered considerable attention within the fields of sports science and health due to its multifaceted benefits on physical performance, recovery, and health markers. As one of the most widely studied dietary supplements, creatine is recognized for its ability to enhance high-intensity exercise performance, increase lean body mass, and support recovery from exercise-induced muscle damage (Amiri et al., 2023; Yamaguchi et al., 2024). However, its effects extend beyond athletic performance, with emerging evidence suggesting benefits for diverse populations, including older adults, postmenopausal women, and individuals with chronic conditions like long COVID (Slankamenac et al., 2024; Chilibeck et al., 2023). This study explores the comprehensive effects of creatine supplementation across a range of physical and health outcomes, offering insights into its applications in both clinical and athletic contexts.

A growing body of research underscores the significant role of creatine in enhancing strength, endurance, and body composition when combined with resistance training (Bonilla et al., 2021; Mills et al., 2020). Additionally, creatine's potential to improve recovery from exercise-induced muscle damage and mitigate fatigue under high-stress conditions highlights its broader utility for occupational and clinical populations (Elstad et al., 2023; Yamaguchi et al., 2024). Despite these advancements, inconsistencies remain regarding its efficacy in endurance sports and synergistic effects with other supplements (Barranco-Gil et al., 2024; Fernández-Landa et al., 2020). Furthermore, its impact on health markers such as oxidative stress, hydration, and brain creatine levels underscores its relevance beyond performance metrics (Amiri et al., 2023; Slankamenac et al., 2024).

This study aims to address critical gaps in the literature by synthesizing findings on the effects of creatine supplementation on physical performance, recovery, and health markers across diverse populations. By integrating results from various contexts, including resistance training, endurance sports, and clinical interventions, this research provides a holistic understanding of creatine's potential applications. The findings have implications for optimizing athletic performance, supporting recovery, and improving quality of life, making creatine supplementation a promising tool in both health and performance sciences.

Methods

A comprehensive systematic literature search was performed using multiple electronic databases, including PubMed, Scopus, Web of Science, and the Cochrane Library, to identify studies investigating the effects of creatine supplementation. The search strategy incorporated a combination of keywords and Medical Subject Headings (MeSH) terms, such as "creatine supplementation," "physical performance," "muscle recovery," "health markers," "body composition," "fatigue management," and "exercise recovery." Boolean operators (e.g., AND, OR) were employed to refine search results systematically. To ensure relevance and quality, filters were applied to include only studies published in English within the last five years (January 2019–November 2024). Editorials and conference abstracts were excluded to focus solely on original research studies.

Reference lists of the included articles were examined to identify additional relevant studies. The inclusion criteria encompassed a diverse range of research designs, including clinical trials, epidemiological studies, mechanistic investigations, meta-analyses, and systematic reviews, provided they demonstrated methodological rigor and relevance to the specified outcomes. Following a multi-stage screening process, 20 high-quality studies meeting these criteria were selected for analysis.

Each selected study was critically appraised for methodological rigor, alignment with the inclusion criteria, and relevance to the effects of creatine supplementation. The findings from these studies were synthesized and analyzed to provide a comprehensive evaluation of the multifaceted impacts of creatine on physical performance, recovery, and health markers across diverse populations.

Results

The findings of this review are categorized into several key domains, elucidating the multifaceted benefits of creatine supplementation in relation to physical performance, recovery, body composition, and overall health. Evidence underscores the pivotal role of creatine in augmenting muscle strength, endurance, and hypertrophy, particularly when integrated with resistance training protocols. Notable improvements were observed in strength-related metrics, including back squat one-repetition maximum (1RM), countermovement jump (CMJ) performance, and leg press endurance, with consistent outcomes reported across diverse populations, such as young adults, older individuals, and athletic cohorts. Furthermore, creatine supplementation demonstrated significant effects on lower-limb fat-free mass and power performance metrics, including Abalakov jump (ABK) height and basketball-specific performance, thereby highlighting its relevance to sports-specific applications.

1. Enhancement of Muscle Strength and Endurance

Resistance training combined with creatine supplementation significantly improved muscle strength in older adults, with the RT + CS group experiencing greater strength gains compared to the RT + P group (Amiri et al., 2023). However, Chilibeck et al. (2023) found no significant differences in muscular strength (bench press and hack squat one-repetition maximum) between creatine and placebo groups, despite improvements in lean tissue mass. While focused on young adults, Mills et al. (2020) reported significant increases in leg press, chest press, and total body strength in the creatine group compared to the placebo group. Additionally, the CS-RT+CrM group demonstrated significant improvements in lower-limb fat-free mass (LL-FFM) and muscular strength, including back squat one-repetition maximum (SQ-1RM) and countermovement jump (CMJ) performance. Notably, effect sizes for whole-body fat-free mass (0.64 vs. 0.16), LL-FFM (0.62 vs. 0.18), and SQ-1RM (1.23 vs. 0.75) were larger in the CS-RT+CrM group compared to the CS-RT-only group, suggesting creatine supplementation enhances training adaptations (Bonilla et al., 2021).

Creatine supplementation significantly enhanced leg press endurance in physically active young adults, with the creatine group showing greater gains compared to the placebo group, though both improved total body endurance over time (Mills et al., 2020). Brooks et al. (2023) observed no significant performance improvements in maximal strength or functional outcomes (e.g., vertical jump or Wingate anaerobic power), but increased lean mass suggests a potential for improved strength endurance with further training. Furtado et al. (2024) reported significant improvements in strength endurance, as evidenced by a greater number of repetitions (+3.4 reps, $p = 0.036$) and higher total work (+199.5 au, $p = 0.038$) during bench press exercises performed at 70% 1RM to concentric failure, without a corresponding increase in maximal strength. Similarly, Feuerbacher et al. (2021) found that creatine supplementation increased total work during a repetitions-to-failure test (RFT) at 70% 1RM (+23.1%, $p = 0.043$, $g = 0.70$), though maximal strength and load-velocity characteristics remained unchanged.

Creatine monohydrate (CrM) supplementation, combined with resistance and plyometric training, led to significant improvements in lower-limb power, demonstrated by increased Abalakov jump (ABK) performance and basketball points scored per game among U16 basketball players (Vargas-Molina et al., 2022). While improvements in specific power measures, such as squat jump (SJ), drop jump (DJ), and countermovement jump (CMJ), were observed in both CrM and control groups, the ABK jump showed the most pronounced effect in the CrM group, reflecting its practical application to sports-specific outcomes (Vargas-Molina et al., 2022). Significant improvements in CMJ were also observed in the CS-RT+CrM group compared to the CS-RT or control groups, further highlighting creatine's impact on jump performance (Bonilla et al., 2021).

2. Improvement in Athletic Performance

Creatine supplementation demonstrated significant improvements in fatigue index during repeated sprint cycling tests in women, particularly during the high hormone phase of the menstrual cycle. Fatigue index decreased by 5.8% in the creatine group compared to a negligible 0.1% in the placebo group, indicating creatine's potential to maintain performance under high hormonal conditions (Gordon et al., 2023). Similarly, creatine improved mean power output and mean running speed during the second half of repeated sprints on a non-motorized treadmill. Specifically, the last three 10-second sprints exhibited a 4.5% increase in power output and a 4.2% to 7.0% increase in speed during the final 5 seconds of each sprint. Additionally, the reduction in speed within each sprint was blunted by 16.2%, reflecting enhanced performance maintenance under fatigue (Bogdanis et al., 2022).

Co-ingestion of creatine (CR) and sodium bicarbonate (SB) significantly enhanced mean power (MP) during the Taekwondo Anaerobic Intermittent Kick Test (TAIKT) compared to CR or SB alone. The combined group showed a greater MP increase ($\Delta = 1.15 \pm 0.28$ W·kg) than CR ($\Delta = 0.43 \pm 0.33$ W·kg, $p < 0.001$) and SB ($\Delta = 0.73 \pm 0.24$ W·kg, $p = 0.03$). Peak power (PP) improved similarly across CR, SB, and CR + SB groups, with no changes observed in the placebo (PLA) or control (CON) groups (Sarshin et al., 2021). Although specific anaerobic effects were not the focus, Fernández-Landa et al. (2020) observed significant improvements in aerobic power during a high-intensity training program, suggesting parallels to anaerobic performance enhancements. Additionally, Elstad et al. (2023) reported that creatine supplementation improved high-intensity repetitive occupational performance in firefighters, with notable gains in rescue and forcible entry tasks.

Several studies failed to demonstrate ergogenic benefits of creatine supplementation in endurance-focused athletes. High-dose, short-term creatine supplementation (20 g/day for 7 days) showed no significant improvements in performance indicators, including critical power, sprint performance, or time trials (3-, 6-, and 12-minute trials), during a high-load training camp in professional cyclists (Barranco-Gil et al., 2024). Similarly, combined creatine and bicarbonate supplementation (CSB) resulted in no significant differences between CSB and placebo groups in 10-m sprint, coordination, or Yo-Yo intermittent recovery level 1 tests (Kim J., 2021). These findings align with Huerta Ojeda et al. (2024), who reported no synergistic or summative effects of creatine, caffeine, and intra-serial variable resistance (I-sVR) on 30-m repeated sprint ability (RSA) or half-back squat performance in soccer players. Furthermore, Fernández-Landa et al. (2020) observed that, despite synergistic effects of creatine and HMB supplementation on aerobic power, there were no improvements in body composition, paralleling results in other endurance-trained populations.

Creatine supplementation has been shown to improve vertical jump performance, reflecting increased explosive power in young adults (Mills et al., 2020).

3. Recovery and Fatigue Management

Although recovery metrics were not directly measured, enhanced performance in repetitive high-intensity tasks suggests that creatine may contribute to improved fatigue management in demanding occupational scenarios (Elstad et al., 2023). Conversely, during a high-load training camp, creatine supplementation did not mitigate increases in fatigue indicators such as delayed-onset muscle soreness or prevent performance declines in critical power (-3.8%), indicating it was ineffective for recovery under high training stress (Barranco-Gil et al., 2024).

Creatine supplementation demonstrated positive effects in contexts requiring enhanced recovery. For example, supplementation combined with glucose improved exercise tolerance in long COVID patients, aligning with findings that highlight creatine's role in managing fatigue in post-viral conditions (Slankamenac et al., 2024). While creatine did not significantly influence heart rate variability (HRV), it helped counteract performance decrements caused by hormonal fluctuations, particularly in the luteal phase, supporting its role in recovery during physiologically challenging conditions (Gordon et al., 2023). Additionally, creatine combined with breathing exercises alleviated post-exertional malaise in long COVID patients, suggesting its utility in prolonged recovery contexts (Slankamenac et al., 2024).

Creatine monohydrate (CrM) supplementation significantly enhanced recovery from exercise-induced muscle damage (EIMD). Improvements were observed in range of motion (ROM) at 24 hours post-exercise and maximum voluntary contraction (MVC) at 0, 48, 96, and 168 hours post-exercise ($p = 0.017–0.047$). Other recovery indicators, including reduced upper arm circumference ($p = 0.002–0.030$), decreased biceps brachii shear modulus ($p = 0.003–0.021$), and lower muscle fatigue levels ($p = 0.012–0.032$), further emphasized CrM's role in mitigating muscle damage and enhancing recovery (Yamaguchi et al., 2024). Creatine supplementation improved training volume and repetitions to failure without significantly altering fatigue index, rate of perceived effort (RPE), or mood state, indicating these gains were achieved without influencing perceived recovery or fatigue levels (Furtado et al., 2024). Additionally, improvements in mean total work and power output during repeated submaximal deep squat bouts were observed following supplementation. While the number of repetitions did not reach statistical significance, the larger effect size ($g = 0.51$) in the creatine condition compared to placebo highlights its potential benefit in fatigue management (Feuerbacher et al., 2021).

4. **Combined Supplementation Effects**

Creatine and sodium bicarbonate (CSB) supplementation significantly improved soccer-specific performance metrics, including 30-m sprint times (-3.6%, $p = 0.007$, ES: 2.3) and arrowhead agility tests (right: -7.3%, $p < 0.001$, ES: 2.8; left: -5.5%, $p = 0.001$, ES: 2.1) compared to the placebo group. However, it remains unclear whether the observed improvements were due to a synergistic interaction between creatine and sodium bicarbonate or the independent effects of each supplement (Kim J., 2021). Similarly, Fernández-Landa et al. (2020) reported synergistic effects of creatine monohydrate (CrM) and HMB on aerobic power at WAT, W4, and W8, reinforcing the potential of combined supplementation strategies to enhance performance.

Creatine supplementation combined with protein and carbohydrates significantly enhanced task-specific performance metrics, including rescue and forcible entry tests, compared to protein and carbohydrate supplementation alone (Elstad et al., 2023). However, the combined use of creatine, caffeine, and intra-serial variable resistance (I-sVR) pre-activation protocols did not produce synergistic improvements in RSA performance among soccer players, highlighting the variability of individual responses to supplementation and pre-activation strategies (Huerta Ojeda et al., 2024).

The combined supplementation of CrM and HMB significantly enhanced aerobic power related to lactate thresholds (WAT, W4, W8), likely due to complementary physiological mechanisms (Fernández-Landa et al., 2020). Additionally, co-administration of creatine with glucose was more effective than creatine alone in increasing brain creatine levels in specific regions, such as the right precentral white matter and left paracentral grey matter, potentially contributing to enhanced recovery in long COVID patients (Slankamenac et al., 2024).

Creatine supplementation reduced plasma ammonia levels by 20.1%, despite improved sprint performance, indicating its role in mitigating energy imbalance during high-intensity exercise without altering aerobic or glycolytic ATP production pathways (Bogdanis et al., 2022). Similarly, co-ingestion of CR and SB significantly lowered post-exercise blood lactate (BL) compared to CR alone or placebo, reflecting enhanced buffering capacity and improved anaerobic performance (Sarshin et al., 2021). Supplementation with β-alanine (BA) or sodium bicarbonate (ALK), combined with BCAAs and creatine malate (TCM), further reduced post-exercise blood ammonia concentrations (BA: -7.9%, $p = 0.013$; ALK: -8.8%, $p = 0.027$), suggesting improved metabolic responses during high-intensity exercise. However, no significant effects were observed on aerobic capacity, blood lactate concentration, hematological parameters, or body composition, limiting its benefits to ammonia regulation (Durkalec-Michalski et al., 2021).

5. Health Markers and Quality of Life

Resistance training combined with creatine supplementation (RT + CS) significantly improved oxidative stress and antioxidant defense markers. The RT + CS group demonstrated a significant reduction in serum oxidative stress markers, including malondialdehyde (MDA) and 8-hydroxydeoxyguanosine (8-OHdG), alongside increased levels of antioxidant markers such as glutathione peroxidase (GPX) and total antioxidant capacity (TAC) (Amiri et al., 2023).

While creatine supplementation did not significantly affect bone mineral density (BMD) at the femoral neck, lumbar spine, or total hip, it improved bone structural integrity by enhancing geometric properties at the proximal femur. Notable improvements included the maintenance of section modulus (a predictor of bone bending strength) and a reduction in buckling ratio (indicative of resistance to cortical bending under compressive loads), suggesting increased protection against fractures (Chilibeck et al., 2023). Additionally, significant improvements in quality of life were observed in both experimental groups, with greater gains in the RT + CS group compared to the RT + P group (Amiri et al., 2023).

Creatine supplementation over eight weeks, particularly when co-administered with glucose, significantly alleviated long COVID symptoms. Improvements were observed in body aches, breathing problems, difficulties concentrating, headaches, and general malaise, with the creatine-glucose combination demonstrating the greatest effects. Large effect sizes were recorded for reducing body aches (1.33), concentration difficulties (0.80), and headaches (1.12) (Slankamenac et al., 2024).

Additionally, creatine supplementation combined with breathing exercises enhanced clinical outcomes in long COVID patients. In the creatine group, tissue creatine levels significantly increased across all measured brain regions, while the control group experienced reductions in key areas such as the right frontal gray matter and left parietal mesial gray matter ($p < 0.05$). Moreover, the mean time to exhaustion improved by 54 seconds post-administration, indicating enhanced physical tolerance and recovery (Slankamenac et al., 2024).

6. Body Composition and Hydration Status

Creatine supplementation demonstrated significant effects on hydration status and body composition across diverse populations. In the RT + CS group, a significant increase in creatinine levels suggested changes in lean mass and hydration (Amiri et al., 2023). Similarly, total body water (TBW) and lean mass (LM) significantly increased in female collegiate dancers following creatine supplementation ($p = 0.024$ and $p = 0.020$, respectively). These changes occurred without concurrent resistance training, underscoring creatine’s potential to optimize body composition in populations facing high physical and academic demands (Brooks et al., 2023).

A subanalysis in postmenopausal women showed a significant increase in lean tissue mass with creatine compared to placebo, further supporting improvements in body composition (Chilibeck et al., 2023). Creatine supplementation also increased body mass (0.99 ± 0.83 kg, $p = 0.007$), consistent with creatine's effects on intracellular water retention (Bogdanis et al., 2022). However, other studies reported no significant changes in body composition despite performance gains, such as in CrM, HMB, and CrM-HMB groups during aerobic training (Fernández-Landa et al., 2020), and among taekwondo athletes using β-alanine (BA), sodium bicarbonate (ALK), BCAAs, and creatine malate (TCM) (Durkalec-Michalski et al., 2021). Similarly, no significant changes in body composition or performance were observed in professional cyclists during high training loads, aligning with the lack of consistent ergogenic benefits in this population (Barranco-Gil et al., 2024).

Creatine supplementation combined with resistance training showed pronounced effects on lower-limb body composition. Increases in muscle thickness across elbow and knee flexors/extensors and ankle plantarflexors were observed in the creatine group, reflecting improvements in both lower-limb and overall body composition (Mills et al., 2020). When combined with cluster-set resistance training (CS-RT), creatine significantly enhanced lower-limb fat-free mass (LL-FFM) and reduced lower-limb fat mass, with greater improvements in the CS-RT+CrM group compared to the CS-RT-only group. These findings highlight the synergistic effects of creatine and resistance training on optimizing body composition (Bonilla et al., 2021).

Discussion

The investigation into the effects of creatine supplementation (CS) and resistance training (RT) reveals significant insights into muscle strength, athletic performance, recovery, and body composition. However, it also underscores areas of inconsistency and gaps in research that warrant further exploration.

Strengths of the findings include robust evidence that CS enhances muscle strength, particularly in lower-limb fat-free mass and power outputs, as highlighted by Bonilla et al. (2021). Additionally, studies like those by Amiri et al. (2023) demonstrate consistent improvements in oxidative stress markers and antioxidant capacity when CS is combined with RT. Furthermore, Vargas-Molina et al. (2022) presents compelling evidence of creatine's sport-specific benefits, such as improved basketball performance metrics. These findings support the role of creatine in optimizing both athletic and general health outcomes.

Nevertheless, several weaknesses emerge. Contradictory results, such as those from Chilibeck et al. (2023) and Brooks et al. (2023), question the uniformity of creatine’s ergogenic effects across populations and performance metrics. For instance, while some studies demonstrate improvements in lean mass, these do not always translate to measurable performance gains, as evidenced by Mills et al. (2020). Similarly, findings related to endurance and aerobic adaptations lack consensus, with studies like Barranco-Gil et al. (2024) failing to show significant improvements in endurance athletes. These discrepancies suggest potential moderating factors, such as population demographics, training protocols, or dosage variability, that are not fully understood.

The need for future research is evident, particularly in understanding the combined effects of creatine with other supplements, as mixed results from Fernández-Landa et al. (2020) and Kim J. (2021) indicate variability in synergistic benefits. Long-term studies assessing the safety and efficacy of creatine in diverse populations, including older adults and those with chronic conditions, are essential. Furthermore, exploring molecular mechanisms, such as its impact on oxidative stress pathways, could refine its application in therapeutic and athletic contexts.

Conclusion

The synthesis of findings in this study emphasizes the multifaceted benefits and limitations of creatine supplementation (CS) when combined with resistance training (RT). Evidence supports its role in significantly enhancing muscle strength, endurance, recovery, and body composition across diverse populations. Notable improvements in lower-limb fat-free mass, oxidative stress markers, and sport-specific performance metrics illustrate its practical applications for athletes and older adults. However, the results highlight inconsistencies, such as variability in outcomes related to maximal strength and aerobic adaptations, underscoring the need for further investigation into population-specific and context-dependent responses.

Disclosure

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The authors declare no conflict of interest.

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