

Improving Performance Through Nutrition: Muscle Recovery Strategies

Beslenme Yoluyla Performansı Artırma: Kas İyileştirme Stratejileri

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Abstract

Muscle recovery and nutrition play a crucial role in enhancing an athlete's performance, maintaining a healthy body and accelerating recovery. Proper nutrition ensures that the body receives essential nutrients such as protein, carbohydrates, fats and other nutrients required for muscle repair and growth, which are critical for muscle recovery and strengthening. A sound nutritional strategy not only enhances an athlete's performance and reduces the risk of injury, but also promotes overall health and well-being. The use of performance-enhancing products is current, but not new to mankind. Substances that enhance performance, reduce fatigue, aid recovery and potentially influence decisiveness has been utilized since ancient times in the form of stimulants, depressants or anabolic agents. In addition, maintaining fluid balance and preventing dehydration are critical not only to an athlete's performance, but also to their overall health. In some sports, in addition to fluid and electrolyte intake, carbohydrate intake is also important, as carbohydrates consumed with fluid are easier to transport and metabolise in the body. In recent years, the effect of coenzyme Q10 supplementation, known for its important role in cellular bioenergetics and redox reactions as well as its antioxidant properties, on post-exercise muscle tissue recovery has attracted attention. While the potential benefits of supplementation in this area are intriguing, further research is necessary to illuminate its effects.

Keywords: Muscle recovery, nutrition, protein, carbohydrate, coenzymeQ10

Öz

Kas iyileşmesi ve beslenme, sporcuların performansını artırmada, sağlıklı bir vücut yapısına sahip olmada ve iyileşme sürecini hızlandırmada önemli bir rol oynar. Doğru beslenme alışkanlıkları, vücudun kas onarımı ve büyümesi için gerekli olan protein, karbonhidrat, yağ gibi temel besin maddelerini almasını sağlar; bu da kasların iyileşmesi ve güçlenmesi için kritik öneme sahiptir. Etkili bir beslenme stratejisi, sporcuların performansını artırırken yaralanma riskini azaltabilir ve genel sağlığı iyileştirebilir. Performans artırıcı ürünlerin kullanımı günceldir, ancak insanlık için yeni değildir. Performansı artıran, yorgunluğu azaltan, iyileşmeye yardımcı olan ve potansiyel olarak kararlılığı etkileyen maddeler, eski zamanlardan beri uyarıcılar, depresanlar veya anabolik ajanlar şeklinde kullanılmaktadır. Buna ek olarak, sıvı dengesini korumak ve dehidrasyonu önlemek sadece bir sporcunun performansı için değil, aynı zamanda genel sağlığı için de kritik öneme sahiptir. Özellikle bazı spor branşlarında sıvı ve elektrolit alımı ile birlikte karbonhidrat tüketimi, besinlerin vücutta taşınması ve metabolize olmasını kolaylaştırır. Son yıllarda, hücre bioenerjitiği ve redoks reaksiyonlarında önemli bir rol oynayan ve aynı zamanda güçlü bir antioksidan olan Koenzim Q10 takviyesinin, spor sonrası kas dokusundaki iyileşme üzerine etkisi giderek daha fazla ilgi çekmektedir. Bu alanda takviye kullanımının potansiyel faydaları önemli olmakla birlikte, daha fazla araştırmaya ihtiyaç duyulmaktadır.

Anahtar Kelimeler: Kas iyileşmesi, beslenme, protein, karbonhidrat, koenzimQ10



INTRODUCTION

Recovery strategies should address the primary causes of fatigue, both within the general population and among athletes community. Physical activity stimulates the metabolism and improves the functioning of the body's systems.^[1,2]

Numerous studies have underscored the significance and effectiveness of proteins, amino acids, emergency intervention principles and metabolic regulators (such as vitamins and minerals) in promoting muscle recovery.^[1-3]

Exercise-induced muscle damage (EIMD) is defined by histopathological alterations in muscle tissue due to skeletal muscle injury, leading to an inflammatory response that reduces the athlete's physical performance and athletic capacity. As a result, muscle regeneration has become a top priority for elite athletes in various sports.^[4]

The implementation of a recovery process through nutritional intervention can be crucial both for the general population and particularly for athletes. Muscle damage can take days to recover.^[5] Faster and more efficient recovery allows athletes to train harder and respond more positively to exercise, which requires adequate nutrient intake.^[6]

Nutrition has a significant impact on stimulating muscle recovery. However, it's important to improve the intake of sufficient energy, nutrients and fluids and to time them appropriately in relation to training and competition schedules.^[7]

These recovery strategies emphasise not only the role of specific nutrients, but also the timing and quantity of intake, which are critical to maximising the benefits of nutritional interventions. A holistic approach that integrates both macro- and micronutrients is essential for effective recovery. It is also important to take into account the psychological aspects of recovery, as mental well-being has a significant impact on physical recovery processes. Addressing psychological resilience and stress management can improve overall recovery and performance.^[8]

In addition, personalised nutrition plans that take into account individual differences in metabolism, nutritional needs and recovery rates can optimise the effectiveness of recovery strategies for athletes.^[9] Such tailored approaches ensure that interventions are not only scientifically sound, but also practically applicable to the individual's unique physiological and psychological profile (**Table 1**).^[8,9]

Key Components of Athletic Nutrition and Recovery

Adequate Protein Intake

During any training or performance session, a decline in muscle function can reduce both the quality and intensity of the activity, putting athletes at risk of injury. It's thought that consuming protein around the time of exercise may improve muscle recovery, however, existing research on this topic has yielded inconsistent results. Whey protein (WP) stands out as

Table 1. Comprehensive Recovery Strategies for Muscle Recovery and Fatigue Management in Athletes

Title	Description
Causes and Mitigation of Fatigue	Fatigue causes should be addressed both in the general population and among athletes. Physical activity stimulates metabolism and improves the functioning of body systems.
Role of Nutrients in Muscle Recovery	Proteins, amino acids, emergency intervention principles, and metabolic regulators (such as vitamins and minerals) promote muscle recovery.
Exercise-Induced Muscle Damage (EIMD)	EIMD is defined by histopathological changes in muscle tissue due to skeletal muscle injury, leading to an inflammatory response that reduces physical performance.
Nutritional Intervention and Recovery	Nutritional intervention can be crucial for both the general population and athletes. Muscle damage can take days to recover. Faster and more efficient recovery allows athletes to train harder and respond more positively to exercise, which requires adequate nutrient intake.
Impact of Nutrition on Muscle Recovery	Nutrition significantly impacts muscle recovery. It's important to ensure sufficient energy, nutrients, and fluids intake and to time them appropriately in relation to training and competition schedules.
Holistic Recovery Strategies	Recovery strategies emphasize not only the role of specific nutrients but also the timing and quantity of intake, which are critical to maximizing the benefits of nutritional interventions.
Psychological Aspects of Recovery	Addressing psychological resilience and stress management can improve overall recovery and performance, as mental well-being significantly impacts physical recovery processes.
Personalized Nutrition Plans	Personalized nutrition plans that consider individual differences in metabolism, nutritional needs, and recovery rates can optimize the effectiveness of recovery strategies for athletes.

a high-quality protein source, abundant in essential amino acids that stimulate muscle protein synthesis (MPS)^[10-13] after exercise, a benefit that exceeds that of other lower quality protein sources.^[14]

One study^[15] investigated the effects of a mixture of WP and casein in an 80:20 ratio, based on the ratio of rapidly and slowly absorbed proteins, reflecting the benchmark for protein quality and nutrient content comparable to what is found in human breast milk (HBM).^[16] Although no beneficial effects on protein metabolism markers were observed, amino acid kinetics indicated that WP was the most effective supplement for increasing plasma leucine concentration. The combination of WP and casein (CAS) did not offer any advantage in amino acid persistence at peak levels compared to WP alone; nevertheless, it was determined that the blend of WP and CAS minimised muscle soreness compared to CAS and placebo groups.^[15]

Two trials investigated the relative efficacy of WP versus vegetable protein on EIMD.^[16,17] They reported that three doses of 0,3 g/kg WP isolate per day for five days after exercise reduced muscle damage in the group studied. Alternatively, pea protein supplementation had a small effect on reducing EIMD.^[16] Collectively, these data endorse the utilization of three doses of 0.3 g/kg WP isolate daily.

The potential of WP to enhance muscle recovery is particularly significant given its high quality protein content, abundant in essential amino acids that are critical for stimulating MPS.^[17] While the existing literature shows mixed results, it is clear that the timing of protein consumption concerning exercise is pivotal for its efficacy.^[18] This underscores the necessity for additional research to optimise protein supplementation strategies, particularly in the context of athletic training and recovery.

Another study^[19] suggests that adequate daily protein intake (1.2-1.6 g/kg or 1.4-2.0 g/kg) and protein intake around the time of exercise promotes muscle recovery. In conclusion, protein supplementation contributes to the enhancement of lean mass, increased strength and improved recovery if the guidelines identified in their research are followed.^[16,19]

Glutamine, along with other amino acids, facilitates a muscle-building state by increasing protein synthesis.^[20,21] Glutamine supplementation has been observed to attenuate "The inflammatory reaction subsequent to eccentric exercise^[22] and to reduce muscle soreness, suggesting a possible association with reduced muscle damage.^[21] Data presented suggest that glutamine supplementation reduces circulating markers of muscle damage, while balancing catabolic and anabolic hormonal responses and stabilising leukocyte counts (**Table 2**).^[23]

Table 2. Effects of Different Types of Protein Supplementation on Muscle Recovery	
Protein Type	Effects and Findings
Whey Protein (WP)	Effective in increasing MPS, supports recovery after exercise.
WP and Casein Mix (80:20)	Most effective in increasing plasma leucine concentration, reduces muscle soreness better than casein and placebo groups.
WP and Plant Protein	Three doses of 0.3 g/kg WP isolate per day reduce muscle damage post-exercise; pea protein has a small effect on reducing EIMD.
General Protein Intake	Adequate protein intake around exercise (1.2-1.6 g/kg or 1.4-2.0 g/kg) promotes muscle recovery, increases lean mass and strength.
Glutamine	Increases muscle protein synthesis, reduces inflammatory reactions, lessens muscle soreness, and stabilizes leukocyte counts.

Carbohydrate Consumption

Carbohydrate (CHO) ingestion during endurance exercise, it has been demonstrated to postpone neuromuscular fatigue and, in particular, improve exercise capacity, depending on the dose administered. In addition, carbohydrate (CHO) supplements can improve exercise performance in specific physical activities of different intensity and duration and adjust biomarkers of exercise-induced muscle damage (EIMD). Numerous studies have examined the impact of carbohydrate (CHO) intake on physical performance, covering different aspects such as repeated sprint performance,^[24] neuromuscular function^[25] and markers linked to exercise-induced muscle damage.^[26,27]

A randomized, double-blind, placebo-controlled, crossover trial in 15 recreational athletes concluded that carbohydrate (CHO) intake just prior to and during short, maximal and repeated sprint exercise did not affect performance or improve training quality.^[22] These findings challenge the previously observed ergogenic effects of CHO on prolonged anaerobic performance. The study provides valuable information for prescribing CHO intake to optimise practical performance-enhancing training. It appears that this form of carbohydrate intake does not improve adenosine triphosphate (ATP) turnover and therefore does not improve anaerobic cycling performance compared to the effects observed with placebo. Therefore, this form of carbohydrate intake does not seem to offer any ergogenic advantage.^[24]

Two studies have shown that a higher carbohydrate intake during an endurance test (up to 120 g/hour) than currently recommended effectively promotes prolonged neuromuscular recovery and mitigates the decline in exercise capacity 24 hours after a mountain marathon, providing an appropriate strategy to modulate EIMD.^[26,27]

Evidence suggests that while carbohydrate (CHO) supplementation may not significantly improve short-term, high-intensity anaerobic performance, it has a pronounced benefit in prolonging endurance and facilitating recovery in longer-duration events.^[28] This difference in efficacy highlights the importance of context-specific nutritional strategies tailored to the nature and duration of exercise. Therefore, practitioners should consider the type of exercise when advising on carbohydrate intake, as the benefits are more apparent in endurance activities than in short bursts of high-intensity effort (**Table 3**).^[29]

Table 3. Effects of Carbohydrate Intake on Exercise Performance and Recovery	
Effect	Description
Enhancing Endurance	Carbohydrate (CHO) intake delays neuromuscular fatigue and increases exercise capacity in endurance exercises.
Ineffective on Short-Term, High-Intensity Performance	CHO intake does not improve performance or training quality in short-term, high-intensity anaerobic exercises.
Supporting Recovery After Exercise	High doses of CHO intake reduce exercise-induced muscle damage (EIMD) and accelerate neuromuscular recovery after prolonged exercises.
Application as a Nutritional Strategy	The benefits of CHO intake vary depending on the type and duration of exercise. Benefits are more pronounced in endurance activities and less so in short, high-intensity efforts.

Fluid Balance

The body's water balance depends on daily fluid intake and fluid loss.^[30] The majority of water (72% by weight) is stored in the muscles.^[31] Because of the extra demands placed on the body by exercise, maintaining the body's water balance is very important for these mechanisms to work effectively.^[30]

The consequences of dehydration include reduced physical and cognitive performance, confusion, impaired gastrointestinal function, impaired renal function, impaired cardiac and haemodynamic function, headaches and deterioration of skin structure. In athletes, in special circumstances or in the presence of chronic diseases, the consequences of dehydration are even more severe.^[32]

Ensuring hydration allows athletes to reduce fluid losses, maintain performance, reduce submaximal heart rate, maintain plasma volume and be less affected by heat stress.^[33] To ensure fluid balance, a fluid and electrolyte intake plan should be established for each athlete before, during and after training, and based on the duration and intensity of training, adjustments should be made as necessary considering factors such as environmental conditions (altitude, temperature, etc.) or competition period (changes in training frequency, competition stress, etc.).^[30,34]

It is of utmost importance to calculate the timing and amount of fluid and electrolytes to be ingested specifically for the athlete; carbohydrates may need to be supplemented to the fluid to be ingested depending on the athlete's training programme and discipline.^[30]

To replace fluid lost through sweating during training and exercise, it's advisable to drink 150-200 ml of water or sports drink every 15-20 minutes throughout the activity.^[35]

The consumption of beverages containing 4-8% carbohydrate is extremely important to maintain hydration and performance, especially during exercise lasting more than an hour.^[30] It is recommended that athletes consume 600-1200 ml/hour of beverages containing carbohydrate (30-60 g/L) and Na (0.5-0.7 g/L) during exercise.^[33]

The strategic approaches to hydration outlined above are essential to optimise performance and maintain physiological function during exercise.^[34] This tailored hydration strategy is essential not only for performance but also for preventing the adverse effects of dehydration, which can severely impact an athlete's health and ability to perform optimally. The inclusion of carbohydrates and electrolytes in fluids, as specified, further enhances the absorption and retention of water, providing the dual benefit of maintaining energy levels and supporting electrolyte balance (**Table 4**).^[35] Thus, proper hydration management is a crucial element of athletic training, particularly in endurance events where sweat loss is significant.

Coenzyme Q10 Supplementation

The CoQ10 molecule is a fat-soluble, vitamin-like compound found extensively throughout the body, and it serves a critical function in cellular bioenergetics. It acts as a cofactor in the mitochondrial respiratory chain, which provides energy to cells.^[36-39]

It (CoQ10) facilitates ATP production by participating in redox reactions.^[36] Besides its function in the mitochondria, CoQ10 has other functions. It acts as a lipid-soluble antioxidant,

Table 4. Hydration strategies and their impact on athletic performance

Aspect	Description
Importance of Hydration	Maintaining the body's water balance is crucial for effective functioning during exercise.
Consequences of Dehydration	Reduced physical and cognitive performance, confusion, impaired gastrointestinal, renal, and cardiac functions, headaches, deterioration of skin structure.
Hydration Benefits for Athletes	Reduces fluid losses, maintains performance, lowers submaximal heart rate, maintains plasma volume, and reduces heat stress impact.
Hydration Strategy	Establish a fluid and electrolyte intake plan before, during, and after training, adjusting for environmental conditions and competition periods.
Fluid Intake Recommendations	Drink 150-200 ml of water or sports drink every 15-20 minutes during exercise.
Carbohydrate-Containing Beverages	Consume beverages with 4-8% carbohydrate content, especially during exercise lasting more than an hour.
Specific Intake Guidelines	Consume 600-1200 ml/hour of beverages containing carbohydrates (30-60 g/L) and sodium (0.5-0.7 g/L) during exercise.
Customized Hydration Plan	Calculate the timing and amount of fluid and electrolytes specific to the athlete's needs; may include carbohydrate supplementation based on training program and discipline.
Overall Hydration Strategy	Essential for optimizing performance, maintaining physiological function, preventing dehydration effects, and supporting energy and electrolyte balance.

protecting DNA,^[40] phospholipids and mitochondrial membrane proteins from lipid peroxidation.^[41,42] CoQ10 also supports the regeneration of vitamins C and E and reduces markers of inflammation. By scavenging reactive oxygen species (ROS), CoQ10 functions as an antioxidant in both mitochondria and lipid membranes.^[38,43]

Recent research has demonstrated the exercise-induced effects of coenzyme Q10 (CoQ10) on glucose metabolism and bone remodelling.^[44,45] Furthermore, the potential benefits of CoQ10 in improving glucose metabolism and bone remodelling suggest its importance not only as a direct energy facilitator, but also in broader physiological adaptations to exercise.^[46] Interestingly, because of its ubiquitous presence at the metabolic level, CoQ10 is expected to exert beneficial effects by improving the performance of exercise-related systems. This molecule has many other potential actions or effects related to exercise and sport,^[47] such as its influence on the nervous system and muscular disorders,^[48] stabilisation of red blood cells (to improve resistance to oxidative stress),^[49] improvement of fluidity,^[50] optimisation of endothelial dysfunction,^[51,52] and possibly even modification of muscle composition.^[53]

The multifaceted role of CoQ10 in supporting athletic performance extends beyond its primary functions within cellular bioenergetics. By enhancing ATP production and providing robust antioxidant protection, CoQ10 helps to maintain cellular integrity and function under the stress of

exercise.^[46] Its involvement in mitigating oxidative stress and supporting mitochondrial health is critical, particularly in high-intensity exercise environments where rapid energy production and efficient recovery are paramount.^[54]

Therefore, the widespread study of CoQ10 and its use as a supplement can be explained by its potential to support energy metabolism and reduce oxidative stress.^[55] In the literature, CoQ10 has been associated with several health benefits, such as supporting cardiovascular health, slowing the ageing process and improving exercise performance.^[56] In addition, many studies have shown that CoQ10 is a safe supplement with minimal side effects, even with long-term use.^[57] For all these reasons, CoQ10 stands out as a supplement of choice, especially in situations where mitochondrial function needs to be supported and oxidative damage needs to be reduced. The potential benefits of this supplement may be particularly important in sports that require high endurance and rapid recovery. CoQ10's role in enhancing exercise performance and speeding up the recovery process makes it a valuable ingredient in sports nutrition. Choosing CoQ10 as a supplement is therefore a logical strategy for optimising energy production and maintaining cellular health (**Table 5**).

Table 5. The Multifaceted Role of CoQ10 in Exercise and Athletic Performance	
Aspect	Description
Basic Function	CoQ10 is a fat-soluble, vitamin-like compound that acts as a cofactor in the mitochondrial respiratory chain, facilitating ATP production.
Antioxidant Role	Protects DNA, phospholipids, and mitochondrial membrane proteins from lipid peroxidation; regenerates vitamins C and E; reduces inflammation markers; scavenges reactive oxygen species (ROS).
Exercise-Induced Effects	Improves glucose metabolism and bone remodelling, suggesting its role in broader physiological adaptations to exercise.
Potential Athletic Benefits	Enhances nervous system and muscular health, stabilizes red blood cells, improves resistance to oxidative stress, optimizes endothelial function, and possibly modifies muscle composition.
Importance in High-Intensity Exercise	Supports rapid energy production and efficient recovery by mitigating oxidative stress and supporting mitochondrial health.
Research Implications	Necessitates further research as an adjunct strategy for athletes, particularly in sports requiring high endurance and rapid recovery.

Other Nutritional Supplements and Their Effects

In addition to Coenzyme Q10 (CoQ10), several other nutritional supplements are commonly used to enhance muscle recovery and athletic performance. Branched-chain amino acids (BCAAs) are essential amino acids that play a significant role in muscle protein synthesis and recovery. Supplementation with BCAAs has been shown to reduce muscle soreness and fatigue following intense exercise. However, the effectiveness of BCAAs in significantly enhancing muscle recovery remains debated in some studies, with mixed results reported on their impact on muscle damage markers and performance.^[58]

Creatine is another popular supplement known for its ability to enhance strength, power, and muscle mass. It works by increasing the availability of ATP, the primary energy currency of cells, particularly during high-intensity, short-duration exercises. While creatine supplementation is generally considered safe and effective, some individuals may experience gastrointestinal discomfort or muscle cramping.^[59]

Omega-3 fatty acids, found in fish oil, have anti-inflammatory properties that can aid in reducing muscle soreness and promoting recovery. Studies suggest that omega-3 supplementation can help mitigate exercise-induced inflammation and support overall cardiovascular health. However, excessive intake of omega-3s can lead to issues such as bleeding disorders and immune system suppression.^[60]

The integration of supplements like BCAAs, creatine, and omega-3 fatty acids further underscores the importance of a comprehensive and personalized approach to sports nutrition. Incorporating these nutritional strategies into training programs can help athletes achieve peak performance, maintain cellular integrity, and ensure efficient recovery. Unlike these supplements, CoQ10 also plays a crucial role in improving cellular energy production efficiency and protecting cells from oxidative damage, making it a potentially more holistic option for supporting athletic performance and recovery.^[55-57]

CONCLUSION

Optimising muscle recovery through nutrition is essential for athletes seeking to improve performance and overall health. Essential nutrients such as proteins, carbohydrates, fats, and micronutrients are critical for muscle repair, growth, and reducing the risk of injury. Proteins and amino acids, often used as supplements, are important ergogenic aids that support health and performance. Carbohydrates are essential for replenishing muscle glycogen stores to enhance performance, with an optimal intake ratio of glucose to fructose of 2:1 for up to 120g/hr. Vitamins, minerals, and antioxidants play a significant role in supporting cellular metabolism and alleviating oxidative stress. Coenzyme Q10 (CoQ10) has shown positive anti-inflammatory and protective effects in response to exercise, although additional research is necessary to fully comprehend its advantages on muscle recovery and performance.

In addition to its role in cellular bioenergetics, CoQ10 is known to enhance mitochondrial function and reduce oxidative damage, which can be particularly beneficial for athletes undergoing intense training regimens. This makes CoQ10 not only valuable for immediate recovery but also for long-term athletic performance. Incorporating these nutritional strategies, including CoQ10 supplementation, into training programs can help athletes achieve peak performance, maintain cellular integrity, and ensure efficient recovery.

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