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The Power of Genetics in Sports Nutrition: Performance and Recovery in Soccer

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Abstract

Personalized nutrition based on an athlete's genetic profile has emerged as an effective strategy for optimizing performance in soccer. This review aims to analyze how nutrigenetic-guided personalized nutrition can enhance soccer performance. Nutrigenetics identifies genetic polymorphisms that influence key physiological processes, including carbohydrate metabolism, muscle recovery, strength generation, aerobic endurance, and thermoregulation. Key genes such as *ACTN3*, *ACE*, *IL6*, *BDKRB2*, and *AMPD1* play critical roles in these processes, directly impacting athletic performance. Personalized nutritional strategies tailored to these genetic insights can optimize glycogen utilization, modulate inflammatory responses, enhance muscle strength and oxygenation, and support adequate hydration. The application of nutrigenetics in soccer not only enhances on-field performance but also reduces injury risk and accelerates recovery, representing a valuable tool for the nutritional management of high-performance athletes.

Introduction

Soccer is characterized by intermittent, variable-intensity exercise, with approximately 88% of match time involving aerobic activity and 12% consisting of high-intensity anaerobic efforts (Bujnovsky et al, 2019). Player performance is further influenced by factors such as the quality of the opposition and the competitive significance of the match (Pimenta et a., 2013). This review examines the primary metabolic challenges faced by soccer players, their potential nutritional implications, and dietary strategies to enhance performance (Basset et al, 2000).

The estimated energy expenditure for a professional soccer player is approximately 1360 kcal per game. A significant decline in performance—around 5%—is observed during the second half compared to the first, primarily due to muscle glycogen depletion (Cermak et al, 2013). Pre-game muscle glycogen levels are critical, with reserves decreasing by 20% to 90% during a match, depending on exercise intensity, environmental temperature, and pre-game dietary composition (Basset et al, 2000).

Dehydration and hyperthermia exacerbate glycogen depletion, accelerating muscle fatigue (Cheung et al, 2010). This is particularly evident in the second half, when players exhibit reduced sprint frequency, increased walking, and decreased total distance covered. Furthermore, soccer players face an elevated risk of micronutrient deficiencies, stemming from oxidative stress induced by repeated muscle exertion, gastrointestinal losses, excessive sweating, frequent travel, circadian rhythm disruptions, and suboptimal dietary patterns (Maughan et al., 2007).

A key nutritional challenge for these athletes is insufficient carbohydrate intake combined with excessive protein and fat consumption. Addressing these issues highlights the critical role of the sports nutritionist. Integrating knowledge of nutrition and genetics into a multidisciplinary team is essential for optimizing the metabolic and physiological parameters required for peak performance and elite athletic achievement.

Genetics

In ancient Greece, Olympic champions were celebrated as demigods, receiving olive branches, substantial monetary rewards—such as 500 drachmas in Athens, a true fortune at the time—and other honors. Sculptors immortalized their likenesses, and poets composed odes to their victories, symbolizing the pinnacle of human potential and societal admiration (Golden, 2004).

In the modern era, the definition of an elite athlete has evolved, shaped by advancements in science, technology, and genetics. A growing body of research has identified "performance-enhancing polymorphisms" (PEPs) within the human genome, which optimize key physiological systems critical for athletic performance (Ahmetov et al,2015). These systems include cardiac and pulmonary efficiency, adrenergic receptor signaling, mitochondrial bioenergetics, vascular regulation, and muscle fiber composition. Among the most studied genes are *ACTN3*, often referred to as the "speed gene" for its role in fast-twitch muscle fibers, and *ACE*, which influences endurance and cardiovascular function (Eynon et al, 2009).

Recent advances in genetic research have expanded our understanding of how genetic variations underpin athletic potential. Studies demonstrate that genetic factors influence a wide range of performance-related traits, including maximal oxygen uptake (VO2 max), energy metabolism efficiency, lactate threshold, neuromuscular coordination, and recovery rates (Ahmetov et al, 2015). For instance, polymorphisms in *PPARGC1A*, which is involved in mitochondrial biogenesis, and *COL5A1*, associated with connective tissue integrity, have been linked to enhanced athletic abilities and reduced injury risk (Posthumus et al, 2016; Ahmetov et al, 2015).

However, genetic influence does not operate in isolation. The interaction between genetic predisposition, environmental factors, and epigenetic modifications plays a pivotal role in shaping an athlete's potential. Lifestyle factors, including personalized nutrition, structured training programs, and recovery protocols, modulate the expression of performance-related genes (Walsh et al, 2014). For example, nutrient timing, the availability of key micronutrients—such as vitamin D, linked to the *VDR* gene—and the consumption of anti-inflammatory foods can influence recovery, adaptation, and overall performance (Lombardo et al, 2017).

Epigenetic modifications, which involve changes in gene expression without altering the underlying DNA sequence, further underscore the adaptability of the human body to environmental stimuli. Tailored interventions leveraging this adaptability can yield substantial performance gains for elite athletes. This dynamic interplay emphasizes the need to integrate genetics with nutritional and training strategies in sports science (Massidda et al, 2012).

While genetic predisposition is estimated to account for 20% to 80% of performance variability depending on the trait, athletic success is inherently multifactorial (Stathis et al, 1994). Psychological resilience, access to resources, and socioeconomic factors also play significant roles in an athlete's journey. Nonetheless, identifying performance-related genetic markers has revolutionized talent identification, injury prevention, and individualized performance optimization (Pitsiladis et al, 2016).

The future of elite sports lies at the intersection of genomics, precision nutrition, and exercise physiology. Continued advancements in genetic research will enable the fine-tuning of training and dietary interventions based on genetic profiles, enhancing performance while promoting athlete longevity and well-being.

Soccer

Soccer is a sport characterized by intermittent, high-intensity activity that combines aerobic endurance and anaerobic power. Approximately 88% of match time involves aerobic activity, with the remaining 12% dedicated to explosive, high-intensity efforts. Player performance is influenced by factors such as the quality of the opposition, the competitive importance of the match, and individual preparation (Bangsbo et al., 2006).

During a professional match, energy expenditure averages approximately 1360 kcal, with glycogen depletion being a primary contributor to fatigue, particularly in the second half. Dehydration, hyperthermia, and inadequate pre-match dietary strategies further exacerbate fatigue, impairing player performance (Cheung et al., 2010).

Assessing the relationship between genetic markers and performance in team sports is inherently complex due to the influence of external factors within a team dynamic. Nevertheless, research has demonstrated a direct correlation between genetic polymorphisms and performance efficiency in soccer players (Massidda et al., 2012). These genetic variations are believed to play a critical role in meeting the diverse demands of power, strength, and endurance required in soccer (Bouchard et al., 1992).

Throughout a typical match, players cover distances ranging from 8 to 12 km, predominantly through walking or light jogging, interspersed with high-intensity sprints (Bassett et al., 2000). This demands exceptional aerobic endurance. Simultaneously, actions requiring explosive power, such as jumping, shooting, and physical challenges for ball possession, necessitate anaerobic strength and speed (Di Salvo et al., 2009).

The growing recognition of the role genetic polymorphisms play in athletic performance has fueled the application of genetic testing in sports science (Hawley et al., 2007). Studies have linked specific polymorphisms, such as those influencing mitochondrial bioenergetics and muscle fiber composition, to athletic performance, offering valuable insights into the genetic determinants of elite soccer performance (MacLellan et al., 2016).

Optimal performance in soccer depends on a combination of physical fitness, strength, endurance, and agility. Meeting these demands is essential to avoid adverse outcomes such as fatigue, cognitive impairment, weight loss, and increased injury risk. Although nutritional interventions are a promising avenue, evidence supporting their direct impact on professional soccer performance remains limited (MacLellan et al., 2016).

Soccer and Genetics: How Personalized Nutrition Enhances Performance

Muscle Recovery and Genes Related to Inflammation

Recovery between training sessions and matches is critical in soccer. Polymorphisms in inflammation-related genes such as IL6 and TNF-α influence post-exercise inflammatory responses, potentially increasing the risk of injury and prolonging recovery time (Cushion et al, 2017). Nutritional interventions rich in anti-inflammatory compounds—such as omega-3 fatty acids and antioxidants found in berries and dark leafy greens—can help mitigate muscle damage and accelerate recovery (Peake et al, 2016).

Muscle Strength and Power: The Role of the ACTN3 Gene

The ACTN3 gene encodes the alpha-actinin-3 protein, which is crucial for high-intensity, short-duration activities like sprints and jumps. Athletes with the “R” variant of this gene typically exhibit superior strength and power, whereas those with the “X” variant may excel in endurance (Montgomery et al, 1999; Moran et al., 2007). Tailored nutrition strategies, such as high-quality protein intake, support muscle mass and recovery. Supplementation with creatine and branched-chain amino acids (BCAAs) may also enhance performance in “R” variant carriers (Jäger et al, 2017).

Oxygenation and Endurance: Variants of the ACE Gene

The ACE gene influences blood pressure regulation and cardiovascular efficiency. Athletes with the “I” variant of this gene are predisposed to greater aerobic endurance, a key attribute in soccer (Williams et al, 2004). Nutritional strategies for these athletes include consuming nitrate-rich foods like beets, which have been shown to enhance muscle oxygenation and endurance performance (Jones, 2014; Lansley et al, 2011).

Hydration and Thermoregulation: The Role of AQP1 and BDKRB2 Genes

Hydration and thermoregulation during intense exercise have genetic components. Polymorphisms in the AQP1 gene (responsible for cellular water transport) and the BDKRB2 gene (involved in vasodilation and temperature control) affect an athlete's susceptibility to dehydration and hyperthermia (Montgomery et al, 2002; Grosell et al., 2011). Personalized hydration strategies, including electrolyte-rich beverages, are essential for maintaining fluid balance in hot conditions (Cheuvront et al, 2010).

Mitochondrial Biogenesis Gene: PPARGC1A

The PPARGC1A gene encodes the PGC-1α protein, a vital regulator of mitochondrial biogenesis and oxidative metabolism. Athletes with favorable polymorphisms in this gene exhibit enhanced aerobic capacity, stamina, and endurance adaptation (Lin et al, 2002). Diets rich in omega-3 fatty acids, polyphenols (berries, green tea), and carbohydrates support mitochondrial function, while CoQ10 and resveratrol supplementation improve mitochondrial efficiency (Packer et al, 2013).

Connective Tissue Gene: COL5A1

The COL5A1 gene encodes type V collagen, a key component of connective tissue. Polymorphisms in this gene can affect flexibility, injury resistance, and the risk of tendinopathies. Nutritional strategies include collagen-rich foods (e.g., bone broth, chicken skin, fish skin) and vitamin C sources (e.g., citrus fruits, bell peppers, strawberries) to enhance collagen synthesis and tendon resilience (Friedrich et al, 2014; Carter et al, 2015).

Personalized Nutrition and Performance Enhancement in Soccer Based on Athlete's Genetics

In recent years, nutrigenetics, the study of how genetic variation influences the body's response to diet — has gained prominence in high-performance sports, particularly in soccer. Personalized nutrition based on the genetic profile of each athlete allows for more precise and effective interventions to improve athletic performance, muscle recovery, and injury prevention.

Muscle Glycogen and Genes Related to Carbohydrate Metabolism

Maintaining adequate muscle glycogen stores is a critical factor for sustained soccer performance, as glycogen depletion is a primary contributor to fatigue, particularly in the second half of a match. Polymorphisms in genes such as AMPD1 (Timmons et al, 2007) and PPARGC1A (Gamboa et al. 2012), which regulate energy metabolism, can significantly influence an athlete's ability to efficiently store and utilize glycogen. Athletes with less efficient variants of these genes may struggle to maintain optimal energy levels during prolonged exercise, impacting performance and recovery. To mitigate this, personalized nutrition strategies can be employed, focusing on the intake of specific nutrients that optimize glycogen stores and utilization (Gamboa et al, 2012).

Pre-'Match Complex Carbohydrates: Athletes with genetic predispositions for reduced glycogen metabolism benefit from a higher intake of complex carbohydrates (e.g., whole grains, oats, quinoa, sweet potatoes) in the 24-48 hours prior to a match. These carbohydrates provide a slow and sustained release of glucose, maximizing glycogen storage in muscle tissue. The recommended intake is 6-10 g of carbohydrates per kilogram of body weight, adjusted based on individual needs and genetic predisposition (Hawley et al, 2015).

In-Macth Simple Carbohydrates: Rapidly digestible carbohydrates such as glucose, sucrose, and maltodextrin are crucial for athletes with low glycogen efficiency during the game. These can be provided through sports drinks, gels, or chews, with the goal of maintaining blood glucose levels and delaying glycogen depletion. Athletes are advised to consume 30-60 g of simple carbohydrates per hour of play, tailored to their genetic profile and metabolic demands (Cermak et al, 2013).

Carbohydrate Loading: For athletes with less efficient glycogen metabolism, a structured carbohydrate-loading protocol can be implemented in the days leading up to a match. This involves increasing carbohydrate intake to about 8-12 g/kg of body weight while tapering physical activity. The goal is to maximize glycogen reserves in muscle and liver tissues, ensuring optimal energy availability during the game (Hawley et al, 2015; Cermak et al, 2013).

Nutrient Timing in Sports Performance: Enhancing Glycogen Utilization
B Vitamins (Coenzymes in Carbohydrate Metabolism):

B vitamins, including B1 (thiamine), B2 (riboflavin), and B6 (pyridoxine), are essential coenzymes in carbohydrate metabolism, facilitating the conversion of carbohydrates into usable energy. Athletes with specific genetic polymorphisms that reduce metabolic efficiency may require higher intake of these vitamins to support optimal glycogen utilization. Food sources: Whole grains, legumes, and leafy greens. These foods should be incorporated into meals, particularly during glycogen-loading phases or recovery periods, to support energy production (Miller et al, 2015; Vuillemin et al, 2002).

Magnesium and Potassium (Electrolyte Balance and Glycogen Storage):

Magnesium is involved in over 300 enzymatic reactions, including those crucial for carbohydrate metabolism and glycogen storage. Potassium plays a complementary role in maintaining electrolyte balance and muscle contractions. Athletes with genetic predispositions affecting energy efficiency or glycogen storage benefit from:

Magnesium-rich foods: Nuts, seeds, spinach.

Potassium rich foods: Bananas, avocados, potatoes. Including these nutrients in post-match recovery meals enhances glycogen replenishment and prevents issues like muscle cramping and fatigue (Volpe et al., 2015; Clarkson et al., 1995).

Caffeine (Glycogen Sparing):

Caffeine promotes fat oxidation, sparing glycogen for later use during prolonged activity. This effect is particularly beneficial for athletes with less efficient glycogen metabolism. The recommended dosage of caffeine is 3-6 mg/kg of body weight, consumed pre-match or at halftime.

- ***Sources***: Coffee, energy drinks, or caffeine supplements.
- ***Consideration***: Genetic variants in the CYP1A2 gene influence caffeine metabolism, determining whether an athlete is a “fast” or “slow” metabolizer. Slow metabolizers should moderate caffeine intake to avoid side effects (Doherty et al., 2004; Burke et al., 2008).

Conclusion

The integration of nutrigenetics into soccer provides a powerful tool for personalizing an athlete’s nutrition, unlocking the potential for enhanced performance and faster recovery. By analyzing the genetic makeup of each player, it becomes possible to tailor dietary strategies that optimize nutrient intake, targeting specific metabolic needs. This precision approach not only maximizes on-field performance but also plays a crucial role in reducing the risk of injuries and accelerating recovery times. As soccer continues to evolve in terms of physical demands, the application of nutrigenetics offers athletes a competitive edge, ensuring they can maintain peak performance throughout a rigorous season and beyond.

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