



Therapeutic approaches to sports nutrition: Balancing health, performance, and recovery – A review

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Abstract

Sports nutrition plays a pivotal role in enhancing athletic performance, supporting training adaptations, and promoting overall health. With increasing scientific evidence supporting personalized nutrition strategies, therapeutic approaches now incorporate macronutrient periodization, targeted micronutrient supplementation, hydration management, and functional foods to optimize performance and recovery. This review synthesizes current knowledge on dietary interventions for athletes, focusing on energy balance, nutrient timing, ergogenic aids, gut health, and recovery-oriented strategies. The paper highlights evidence-based therapeutic practices that help athletes achieve optimal performance while preventing fatigue, injury, and long-term health issues.

Keywords: Therapeutic nutrition, foods, diet, sports, athletes, macronutrients

Introduction

Sports nutrition has evolved from basic dietary recommendations to advanced therapeutic strategies tailored to individual needs, sport type, training load, and physiological demands. Athletes require specialized diets that support muscle repair, energy production, neurological functioning, and immune competence. As training intensifies, dietary inadequacies can impair performance, reduce endurance, increase fatigue, and elevate the risk of injuries. Therapeutic sports nutrition integrates scientific principles to maintain health, enhance performance, and accelerate recovery, forming a multidimensional system involving macronutrient modulation, hydration strategies, and evidence-based use of performance-enhancing dietary supplements. This review explores these therapeutic approaches and their potential benefits.

Energy Balance and Macronutrient Optimization

1. Energy Requirements in Athletes

Athletes often require energy intakes significantly higher than sedentary individuals, as maintaining an optimal energy balance ensures adequate fueling for training while preventing hormonal imbalance, injury susceptibility, and impaired immune function. Low Energy Availability (LEA) has been strongly associated with the development of Relative Energy Deficiency in Sport (RED-S), a condition that adversely affects metabolic rate, menstrual function, bone health, immune capacity, and psychological well-being. Understanding and addressing LEA is therefore essential for safeguarding both athletic performance and long-term health.

2. Carbohydrates: The Primary Fuel

Carbohydrates are central to maintaining muscle glycogen stores, which are critical for supporting endurance and high-

intensity activities. Therapeutic strategies for optimizing carbohydrate intake in athletes focus on maximizing glycogen availability, supporting sustained energy release, and enhancing recovery. Carbohydrate loading before endurance events significantly increases muscle glycogen stores, enabling athletes to perform longer and delay fatigue. During post-exercise recovery, consuming high-glycemic index (GI) foods promotes rapid glycogen resynthesis and accelerates muscle restoration. Periodized carbohydrate intake—alternating between high-carb days to fuel intense training sessions and low-carb sessions to promote metabolic flexibility—helps athletes adapt to varying training demands and improve performance outcomes (Impey *et al.*, 2018) ^[22]. Additionally, consuming easily digestible carbohydrate sources such as sports drinks, energy gels, or fruits during prolonged exercise provides quick energy, maintains blood glucose levels, and prevents premature exhaustion, thereby supporting sustained endurance.

3. Protein: Muscle Repair and Adaptation

Athletes require higher protein intakes (1.2–2.0 g/kg/day) to support muscle repair, recovery, and strength development, and several therapeutic strategies help optimize these benefits. Evenly distributing protein intake across meals enhances muscle protein synthesis throughout the day, rather than concentrating it in one or two large servings (Areta *et al.*, 2013) ^[2]. Supplementation with high-quality proteins such as whey, casein, or soy provides essential amino acids that promote rapid or sustained muscle rebuilding depending on the protein type. Combining protein with carbohydrates after training further improves recovery by stimulating insulin release, enhancing amino acid uptake, and accelerating glycogen replenishment (Ivy, 2004) ^[23]. Additionally, consuming casein before sleep

offers a slow-release source of amino acids, supporting overnight muscle protein synthesis and improving overall recovery and adaptation to training.

4. Fats: Long-Duration Energy and Hormonal Health

Healthy fats play a vital role in sports nutrition by providing sustained energy for ultra-endurance activities and supporting essential hormonal functions that regulate metabolism, recovery, and overall health (Rodriguez, DiMarco, & Langley, 2009) ^[42]. Therapeutic recommendations emphasize the inclusion of omega-3 fatty acids, known for their potent anti-inflammatory properties that help reduce exercise-induced muscle damage and support cardiovascular health (Philpott, Donnelly, & Walshe, 2018) ^[36]. Athletes are advised to avoid very low-fat diets (<20% of total energy), as such restrictions can impair hormone production, reduce nutrient absorption, and negatively impact performance. Instead, incorporating nutrient-dense fat sources such as nuts, seeds, avocados, and fatty fish ensures an adequate supply of essential fatty acids, promotes long-lasting energy availability, and contributes to improved recovery and performance outcomes.

Micronutrient Strategies in Sports Nutrition

1. Iron, Calcium, and Vitamin D

Micronutrients play an essential role in sports nutrition, as they support a wide range of physiological processes fundamental to athletic performance, recovery, and overall health (Rodriguez, DiMarco, & Langley, 2009) ^[42]. Among these, iron, calcium, and vitamin D are particularly important due to their direct involvement in oxygen transport, bone health, muscle function, and metabolic regulation. Ensuring optimal intake of these micronutrients is crucial for athletes, who often face higher nutrient demands due to intense training, increased sweat losses, and elevated energy expenditure. Effective micronutrient strategies involve regular monitoring, individualized supplementation when necessary, and a diet rich in bioavailable nutrient sources to prevent deficiencies that may compromise performance and lead to long-term health issues.

Iron is one of the most critical micronutrients for athletes, especially endurance athletes and menstruating females. It is a key component of hemoglobin and myoglobin, molecules responsible for oxygen transport and storage. Iron deficiency can lead to anemia, reduced aerobic capacity, fatigue, and impaired performance. Strategies to maintain adequate iron levels include consuming heme-iron sources such as lean meats and seafood, as well as non-heme iron from plant foods like legumes and leafy vegetables combined with vitamin C to enhance absorption (McCormick *et al.*, 2020) ^[31]. Periodic blood tests and iron supplementation may be necessary for high-risk athletes, particularly those experiencing heavy training loads or recurrent low ferritin levels.

Calcium plays a central role in bone mineralization, muscle contraction, and nerve conduction. Athletes with inadequate calcium intake face a greater risk of stress fractures, muscle cramps, and long-term issues like osteoporosis (Nattiv *et al.*, 2007) ^[33]. Milk, yogurt, cheese, fortified plant-based beverages, and leafy greens provide excellent dietary calcium sources. Ensuring adequate intake is especially important for athletes with high training volumes, low energy availability, or restrictive eating patterns.

Vitamin D works synergistically with calcium, enhancing its absorption and supporting bone health, immune function, and muscle strength (Close *et al.*, 2013) ^[8]. Many athletes, even those living in sunny regions, exhibit suboptimal vitamin D levels due to indoor training schedules or limited sun exposure. Therapeutic strategies include moderate sun exposure, vitamin D-fortified foods, and supplementation when needed. Maintaining optimal vitamin D status improves muscle function, reduces injury risk, and enhances immune resilience, making it a vital component of sports nutrition (Larson-Meyer & Willis, 2010) ^[28].

2. Antioxidants

Antioxidants play a crucial role in sports nutrition by helping athletes manage the elevated oxidative stress that accompanies intense or prolonged exercise (Powers, Radak, & Ji, 2016) ^[39]. During high-intensity physical activity, the body generates increased levels of reactive oxygen species (ROS), which, if not balanced by antioxidant defenses, can lead to muscle damage, fatigue, and impaired recovery. Whole-food antioxidants—such as vitamin C, vitamin E, and a wide array of polyphenols found in fruits, vegetables, nuts, seeds, and plant-based beverages—contribute significantly to neutralizing these free radicals while also supporting immune function and reducing inflammation (Pingitore *et al.*, 2015) ^[38]. However, emerging research indicates that while antioxidants are essential, the source and dosage matter considerably for athletic performance. High-dose antioxidant supplements can blunt beneficial training adaptations, particularly those related to mitochondrial biogenesis and improved insulin sensitivity, by reducing the oxidative signals that trigger physiological improvements (Paulsen *et al.*, 2014) ^[35]. As a result, relying on food-based sources rather than concentrated supplements is considered the most effective therapeutic strategy. Whole foods provide a complex matrix of antioxidants, phytochemicals, and nutrients that work synergistically to protect cells without disrupting the adaptive processes essential for endurance, strength, and metabolic efficiency. Incorporating colorful fruits, vegetables, green tea, berries, turmeric, nuts, and dark chocolate into daily meals ensures adequate antioxidant intake while promoting overall health, recovery, and long-term performance.

3. B Vitamins

B vitamins play a pivotal role in sports nutrition due to their essential involvement in energy metabolism, red blood cell formation, and neurological function—processes that are vital for athletic performance. The B-complex vitamins, including thiamine (B1), riboflavin (B2), niacin (B3), pyridoxine (B6), folate (B9), and cobalamin (B12), act as coenzymes in metabolic pathways responsible for converting carbohydrates, proteins, and fats into usable energy (Manore, 2017) ^[30]. Athletes have higher metabolic demands, and inadequate intake of these vitamins can impair the efficiency of energy production, leading to early fatigue, reduced endurance capacity, and compromised training outcomes. Additionally, vitamins B6, B9, and B12 play an important role in the synthesis of red blood cells and hemoglobin, which support oxygen transport to working muscles. Deficiencies in these nutrients may result in anemia-like symptoms or decreased aerobic performance. Neuromuscular function also depends heavily on adequate levels of B vitamins, particularly B6 and B12, which are

involved in neurotransmitter synthesis and nerve conduction (Kennedy, 2016) [26]. Athletes with high energy expenditures, those following restrictive diets (such as vegan or weight-class sports), and individuals with increased sweat losses may be at greater risk of deficiency. Therapeutic strategies to maintain optimal B vitamin status include consuming a balanced diet rich in whole grains, legumes, dairy products, eggs, leafy greens, and lean meats, along with fortified foods when necessary. In certain cases—such as endurance athletes or those with documented deficiencies—targeted supplementation may be beneficial. Ensuring adequate B vitamin intake supports efficient metabolism, enhances endurance, and contributes to overall neuromuscular health, making these micronutrients indispensable for athletic performance and recovery.

Hydration and Electrolyte Balance

Hydration and electrolyte balance are fundamental pillars of sports nutrition, as they directly influence thermoregulation, cardiovascular performance, muscle function, and mental clarity during exercise. Even mild dehydration can impair endurance, reduce strength, slow reaction time, and increase the risk of heat-related illnesses, making a structured hydration strategy essential for athletes (American College of Sports Medicine (ACSM), 2016) [1]. Pre-hydration typically involves consuming 5–7 mL/kg of fluid about four hours before activity to ensure proper hydration while allowing the body to excrete any excess (ACSM, 2016). During exercise, consuming 150–350 mL of fluid every 15–20 minutes—adjusted for sweat rate, environmental heat, and exercise duration—helps minimize fluid loss and prevents performance declines. Sodium replacement becomes increasingly important during prolonged or intense activity, especially for athletes who lose large amounts of salt through sweat, as sodium supports fluid retention, nerve signaling, and the prevention of hyponatremia caused by excessive water intake (Hew-Butler *et al.*, 2015) [18]. Post-exercise rehydration should focus on restoring both fluids and electrolytes, with oral rehydration solutions (ORS) offering a more effective recovery option than plain water by replenishing sodium, potassium, and glucose to enhance absorption and restore balance. Maintaining optimal hydration and electrolyte levels enhances physical performance, reduces fatigue, supports faster recovery, and protects athletes from heat-related complications, making it a cornerstone of therapeutic sports nutrition.

Nutrient Timing for Performance and Recovery

1. Pre-Exercise Nutrition

Pre-exercise nutrition plays a vital role in preparing the body for optimal performance by ensuring sufficient energy availability, stabilizing blood glucose levels, and supporting sustained endurance throughout the activity. Consuming a balanced meal 2–4 hours before exercise allows adequate time for digestion while providing athletes with the necessary macronutrients to fuel their training (American College of Sports Medicine [ACSM], 2016) [1]. Carbohydrates serve as the primary energy source, helping to maximize glycogen stores and prevent early fatigue during high-intensity or prolonged workouts. Including lean protein supports muscle repair and reduces exercise-induced muscle breakdown, contributing to improved recovery and training adaptations. Moderate amounts of healthy fats add satiety and provide a slow-releasing energy source without

causing gastrointestinal discomfort when timed properly. This balanced approach helps maintain metabolic efficiency, stabilize energy levels, and enhance both physical and cognitive readiness for exercise. Proper pre-exercise nutrition is especially essential for endurance athletes, those engaging in high-intensity sessions, and individuals training in the early morning when overnight fasting may have depleted glycogen stores. By thoughtfully selecting nutrient-dense foods and timing intake appropriately, athletes can significantly enhance their overall performance, delay fatigue, and improve training outcomes.

2. During Exercise

During exercise, especially in endurance events lasting longer than 60 minutes, strategic carbohydrate intake is essential to maintain blood glucose levels, delay fatigue, and sustain optimal performance. As glycogen stores become depleted during prolonged activity, consuming 30–60 g of carbohydrates per hour helps replenish circulating glucose and supports continuous energy production. For ultra-endurance events, where energy demands are significantly higher, athletes can consume up to 90 g of carbohydrates per hour by using multiple transportable carbohydrate sources—typically a combination of glucose and fructose. This dual-source approach enhances carbohydrate absorption rates in the intestine, reduces the risk of gastrointestinal discomfort, and increases the total carbohydrate oxidation capacity compared to single-source intake. Sports drinks, gels, chews, and easily digestible fruits are commonly used to meet these requirements during prolonged exercise. Maintaining an adequate carbohydrate supply during activity not only supports sustained physical output but also helps preserve cognitive function, coordination, and decision-making abilities, all of which are crucial for athletic performance in long-duration events (Cermak & van Loon, 2013) [7].

3. Post-Exercise Recovery

The immediate post-exercise period, often referred to as the “anabolic window,” is considered a crucial phase for maximizing recovery, particularly within the first 30–60 minutes after training (Ivy, 2004) [23]. During this time, muscles are highly receptive to nutrient uptake, making targeted nutritional strategies especially effective for restoring energy stores, repairing muscle tissue, and reducing inflammation. Consuming 1.0–1.2 g/kg of carbohydrate helps replenish depleted glycogen stores quickly, which is essential for athletes engaging in high-intensity or frequent training sessions. Pairing this with 20–40 g of high-quality protein stimulates muscle protein synthesis, supports tissue repair, and promotes lean muscle development. Rehydration with fluids and electrolytes is equally important for restoring sweat losses, maintaining blood volume, and supporting optimal physiological function. Including antioxidant-rich foods such as berries, turmeric, and green tea provides natural compounds that help combat exercise-induced oxidative stress and inflammation without interfering with the adaptive processes that improve performance. Together, these strategies accelerate recovery, enhance training adaptations, and prepare the body for subsequent exercise sessions.

Therapeutic Use of Ergogenic Aids

1. Creatine Monohydrate

Creatine monohydrate is one of the most extensively researched and clinically supported ergogenic aids in sports nutrition, widely recognized for its significant benefits in enhancing strength, power output, and muscle hypertrophy (Kreider *et al.*, 2017) [27]. As a naturally occurring compound stored in skeletal muscle, creatine plays a key role in the phosphocreatine energy system, which fuels short bursts of high-intensity activity such as sprinting, weightlifting, and explosive movements (Buford *et al.*, 2007) [6]. Supplementation increases intramuscular creatine stores, allowing athletes to perform more repetitions, recover faster between sets, and sustain higher training intensities—ultimately contributing to greater performance adaptations and muscle growth (Branch, 2003) [5]. The therapeutic use of creatine monohydrate typically follows a well-established protocol. The most common and simplest approach is a maintenance dose of 3–5 g per day, which is sufficient to gradually elevate and maintain muscle creatine saturation over time (Kreider *et al.*, 2017) [27]. For athletes seeking faster results, an optional loading phase can be used, involving 20 g per day divided into 4 doses for 5–7 days, which rapidly increases muscle creatine levels but is not required for long-term effectiveness (Buford *et al.*, 2007) [6]. After the loading phase, athletes' transition to the standard 3–5 g/day maintenance dose. Creatine monohydrate is considered safe for long-term use, with extensive evidence supporting its efficacy and minimal side effects when consumed within recommended guidelines (Rawson & Persky, 2007) [41]. Adequate hydration is advised, as creatine increases intracellular water content. Overall, creatine remains one of the most effective therapeutic supplements for athletes aiming to improve power, strength, and training adaptations.

2. Caffeine

Caffeine is a widely used and well-supported ergogenic aid known for its ability to enhance endurance, improve alertness, and boost sprint and high-intensity performance (Grgic *et al.*, 2020) [15]. Its primary mechanisms include stimulating the central nervous system, reducing perceived exertion, and increasing the mobilization of fatty acids for energy, thereby sparing muscle glycogen during prolonged exercise (Spriet, 2014) [46]. Caffeine also enhances reaction time, focus, and neuromuscular function, making it particularly beneficial for sports that require both physical and cognitive precision (Duncan *et al.*, 2019) [12]. Research consistently shows that caffeine can improve performance across a range of activities, including endurance events, intermittent team sports, and short-duration, high-intensity efforts (Southward *et al.*, 2018) [45]. The effective therapeutic dose of caffeine is 3–6 mg/kg of body weight, typically consumed 30–60 minutes before exercise to allow sufficient time for absorption and peak concentration (Goldstein *et al.*, 2010) [14]. Athletes may obtain caffeine through coffee, tea, energy drinks, caffeine tablets, or caffeinated gels, depending on preference and tolerance. Individual sensitivity varies, so athletes are encouraged to test their caffeine intake during training rather than trying new dosages on competition day. Higher doses do not necessarily yield greater benefits and may increase the risk of side effects such as jitteriness, gastrointestinal discomfort, increased heart rate, or sleep

disturbances. When used strategically and responsibly, caffeine remains one of the most effective therapeutic ergogenic aids for enhancing both physical performance and mental readiness.

3. Beta-Alanine

Beta-alanine is a well-established ergogenic aid known for its ability to enhance performance during high-intensity exercise by buffering muscle acidosis (Hobson *et al.*, 2012; Saunders *et al.*, 2017) [20, 43]. During intense physical activity, the accumulation of hydrogen ions leads to a drop in muscle pH, contributing to fatigue and reduced power output (Artioli *et al.*, 2010) [3]. Beta-alanine supplementation increases intramuscular carnosine levels, a dipeptide that serves as a critical pH buffer, delaying the onset of fatigue and allowing athletes to sustain high-intensity efforts for longer periods. This makes beta-alanine particularly beneficial for sports involving repeated sprints, interval training, combat sports, and events lasting 1–4 minutes, such as middle-distance running or rowing.

The typical therapeutic protocol involves taking 4–6 g of beta-alanine per day for at least 4 weeks, as consistent intake is necessary to elevate muscle carnosine concentrations (Saunders *et al.*, 2017) [43]. Doses are often divided throughout the day to minimize paresthesia—a harmless tingling sensation that can occur with larger single doses (Harris *et al.*, 2006) [17]. Longer supplementation periods, extending to 8–12 weeks, may yield even greater increases in carnosine levels and performance benefits. Beta-alanine is most effective when combined with a structured training program and can also complement other ergogenic aids like creatine (Hobson *et al.*, 2012) [20]. Overall, beta-alanine is a safe and effective strategy for athletes seeking improved high-intensity performance and greater resistance to muscle fatigue.

4. Nitrate (Beetroot Juice)

Dietary nitrate, commonly consumed through beetroot juice, has emerged as a highly effective ergogenic aid for improving cardiovascular efficiency and endurance performance (Jones, 2014; Domínguez *et al.*, 2017) [11, 24]. Nitrate is converted in the body to nitric oxide (NO), a molecule that plays a vital role in vasodilation, enhancing blood flow to working muscles and improving oxygen delivery (Lundberg *et al.*, 2009) [29]. This increased oxygen efficiency allows athletes to perform the same workload with reduced oxygen cost, thereby improving stamina and delaying fatigue (Jones *et al.*, 2018) [25]. Beetroot juice and other nitrate-rich foods such as spinach, arugula, and celery have been shown to benefit endurance events, high-intensity intermittent exercise, and even resistance training by enhancing muscle contractility and reducing perceived exertion (Hoon *et al.*, 2013; Domínguez *et al.*, 2017) [11, 21]. The recommended therapeutic dose is 300–600 mg of nitrate, typically consumed 2–3 hours before performance to allow sufficient time for the nitrate–nitrite–NO conversion pathway to take effect (Jones, 2014) [24]. For consistent benefits, athletes may incorporate beetroot juice or nitrate supplements into their routine for several days leading up to competition (Domínguez *et al.*, 2017) [11]. Individual responses can vary, and some athletes may experience gastrointestinal discomfort depending on the form or concentration consumed (Hoon *et al.*, 2013) [21]. Nonetheless, nitrate supplementation is considered safe,

natural, and highly effective when used appropriately, making it a valuable tool for athletes aiming to improve endurance, increase training efficiency, and enhance overall performance (Jones *et al.*, 2018) ^[25].

Gut Health and Functional Foods

1. Probiotics and Prebiotics

Athletes, particularly endurance runners, are often prone to gastrointestinal discomfort due to factors such as intensified training, altered blood flow to the gut during exercise, and dietary fluctuations (Costa *et al.*, 2017) ^[19]. In this context, probiotics and prebiotics serve as valuable therapeutic tools for maintaining gut health and supporting overall performance. Probiotics—beneficial live microorganisms found in foods like yogurt, kefir, and fermented products—help strengthen gut integrity by reinforcing the intestinal barrier, thereby reducing the likelihood of gastrointestinal disturbances such as bloating, cramps, or diarrhea during exercise (Hill *et al.*, 2014; West *et al.*, 2015) ^[19, 49]. They also play a significant role in modulating inflammation, which is crucial for athletes experiencing repeated physical stress (Shing *et al.*, 2014) ^[44]. Improved nutrient absorption is another key benefit, as a healthy gut microbiome enhances the assimilation of vitamins, minerals, and amino acids essential for energy metabolism and recovery. Additionally, probiotics support immune function by promoting a balanced microbial environment, reducing the frequency of upper respiratory tract infections—a common issue among athletes undergoing intense training blocks (Pyne *et al.*, 2015) ^[40].

Prebiotics, such as inulin and fructooligosaccharides, complement probiotic action by serving as food for beneficial gut bacteria. These non-digestible fibers selectively stimulate the growth of healthy microbes, contributing to improved digestion, reduced inflammation, and enhanced resilience against infections (Gibson *et al.*, 2017) ^[13]. By fostering a diverse and stable microbiota, prebiotics help athletes maintain better digestive comfort, particularly during endurance activities where gut stress is common (Davison *et al.*, 2016) ^[10]. Together, probiotics and prebiotics create a synergistic effect—supporting gut integrity, reducing illness risk, and promoting optimal nutrient absorption—ultimately contributing to improved athletic performance and recovery (Morrison & Preston, 2016) ^[32].

2. Functional Foods

Functional foods such as tart cherry juice, turmeric, ginger, dark chocolate, and green tea are rich in bioactive compounds with strong anti-inflammatory and antioxidant properties (Bell *et al.*, 2021) ^[4]. These foods help reduce exercise-induced oxidative stress, support muscle repair, and improve overall recovery time by modulating inflammatory pathways and enhancing antioxidant capacity. Regular inclusion of these functional foods in the diet can enhance post-exercise healing and promote better athletic performance, particularly for athletes engaging in high-intensity or endurance training (Pan *et al.*, 2016; Stover & Murray, 2008) ^[34, 47].

Recovery-Focused Therapeutic Nutrition

Recovery nutrition plays a crucial role in restoring glycogen levels, repairing muscle tissue, and minimizing inflammation after exercise. Combining protein with

carbohydrates enhances muscle protein synthesis while accelerating glycogen replenishment, making it a foundational strategy for post-workout recovery. Omega-3 fatty acids further support this process by reducing exercise-induced muscle soreness and inflammation (Tinsley *et al.*, 2021) ^[48]. Polyphenol-rich foods such as berries, pomegranate, and curcumin help combat oxidative stress, promoting faster recovery and improved overall performance. Adequate sleep, supported by natural sources of melatonin like cherries and walnuts, enhances hormonal recovery and tissue repair (Pigeon *et al.*, 2010) ^[37]. Additionally, maintaining proper hydration and replenishing electrolytes is essential for restoring fluid balance, supporting nerve function, and ensuring optimal post-exercise recovery.

Personalized Nutrition Approaches

Athletes benefit most from personalized nutrition plans tailored to their unique physiological and performance needs. Factors such as body composition, metabolic rate, training periodization, and specific health conditions—such as anemia—significantly influence dietary requirements and recovery strategies. Additionally, sport-specific demands dictate energy intake, macronutrient distribution, hydration needs, and supplementation protocols. Advancements in technology, including continuous glucose monitoring (CGM), genetic testing, and metabolic profiling, now offer deeper insights into individual responses to food and exercise (Guest *et al.*, 2019) ^[16]. These tools enable highly precise nutrition planning that optimizes performance, accelerates recovery, and reduces injury risk.

Conclusion

Therapeutic sports nutrition integrates multi-dimensional strategies that balance health, performance, and recovery. By focusing on energy balance, macronutrient periodization, targeted micronutrient support, hydration, nutrient timing, and use of functional foods and ergogenic aids, athletes can significantly improve training outcomes while protecting long-term health. Personalized and evidence-based nutritional interventions represent the future of sports nutrition, ensuring optimal performance and resilience across all levels of athletic activity.

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