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Probiotics in Sports: Modulating the Microbiome for Performance and Health

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Abstract
Background
The human gut microbiome-a dynamic ecosystem of bacteria, viruses, fungi, and archaea—is integral to digestion, immune modulation, metabolism, and systemic health. Its composition is shaped by perinatal factors, genetics, environment, diet, physical activity, and probiotic interventions. Modulating the microbiome through lifestyle and nutritional strategies offers potential for disease prevention and enhanced athletic performance.
Aim
This review synthesizes current evidence on factors influencing gut microbiota composition across the lifespan, the systemic impacts of dysbiosis, and the roles of diet, physical activity, and probiotics-particularly in athletic populations-in fostering a health-promoting microbiome.
Material and Methods
A narrative review was conducted using peer-reviewed studies, meta-analyses, and clinical trials sourced from PubMed, Scopus, and Web of Science. Topics included microbiome development, lifestyle and dietary influences, exercise-related microbiome adaptations, and probiotic applications.
Results
Perinatal factors such as delivery mode, breastfeeding, and antibiotics shape early microbiota with long-term health effects. Diet is a primary modulator: fiber- and polyphenol-rich diets enhance microbial diversity, whereas high-protein, low-fiber diets may impair gut health in athletes. Physical activity modifies microbiota structure and function; regular exercise promotes beneficial SCFA-producing taxa, strengthens gut barrier integrity, and supports immune and neurocognitive health. Probiotic supplementation improves gastrointestinal and dermatological conditions, modulates inflammation, and enhances athletic recovery and resilience.
Conclusions
The gut microbiome is a key determinant of systemic health. Targeted diet, structured physical activity, and personalized probiotic use can optimize microbiota function. In athletes, integrating microbiome profiling with individualized nutrition may enhance performance and recovery.

Keywords: gut microbiota, microbiome composition, physical activity, exercise, diet, probiotics, athletic performance, short-chain fatty acids (scfas), gut-brain axis, gut barrier integrity, dysbiosis, immune modulation, sports nutrition, personalized nutrition

1. Introduction

The human gut microbiome plays a pivotal role in modulating systemic physiology, including metabolism, immunity, and neuroendocrine function-factors that are critically relevant to athletic performance, recovery, and resilience. Its composition is shaped by early-life factors, genetic background, environmental exposures, dietary patterns, physical activity, and probiotic interventions. Emerging evidence highlights the gut microbiome as a dynamic mediator of exercise adaptation and metabolic efficiency, with implications for optimizing sports nutrition and training outcomes.

This review examines the current understanding of microbiota determinants across the lifespan and evaluates the impact of diet, exercise, and probiotics on microbiome composition and function, with particular emphasis on strategies to enhance health and performance in athletic populations.

2. Factors influencing gut microbiota composition

Perinatal and early life factors

The earliest influences on gut microbiota composition begin in utero, challenging the traditional notion of a sterile fetal environment. Studies have detected microbial DNA in the placenta and amniotic fluid, suggesting that colonization may start before birth (Aagaard et al., 2014). However, the mode of delivery at birth remains a pivotal determinant: vaginally delivered infants are inoculated primarily with beneficial vaginal microbiota such as *Lactobacillus* and *Bacteroides*, whereas cesarean section (CS) infants harbor skin-associated and environmental microbes (Hill et al., 2017; Stinson et al., 2018). This early microbial difference has been associated with an elevated risk of immune-mediated diseases later in life, including asthma, allergies, and obesity (Stinson et al., 2018). Furthermore, infant feeding practices critically shape the developing microbiome: breastfeeding promotes the colonization of *Bifidobacterium* and *Lactobacillus* species, attributed to the presence of human milk oligosaccharides that serve as selective prebiotics (Cresci & Bawden, 2015). In contrast, formula feeding leads to a more diverse but less specialized microbial environment. Other perinatal factors, such as antibiotic exposure, especially during or shortly after birth, can significantly delay microbial maturation and decrease diversity, effects that can persist for years (Fouhy et al., 2019).

Lifestyle, diet and physical activity across the lifespan

After infancy, the gut microbiota becomes relatively stable but remains sensitive to major environmental and lifestyle factors. Diet is a principal modulator: individuals adhering to diets rich in fiber and plant-based foods exhibit a microbiota enriched with *Prevotella* species, while high-fat, high-protein Western diets promote *Bacteroides*-dominated enterotypes (Salazar et al., 2014). Dietary interventions using probiotics, prebiotics, and specific nutrient formulations have shown promise in restoring microbial balance, especially at critical periods like infancy and aging (Salazar et al., 2014). Emerging research highlights the role of physical activity as an independent factor influencing gut microbiota structure. Athletes, compared to sedentary individuals, display greater microbial diversity, increased abundance of health-promoting bacteria (e.g., *Akkermansia*, *Faecalibacterium*), and enhanced metabolic functionality, including higher production of short-chain fatty acids, crucial for gut health and systemic immunity (Mohr et al., 2020). This demonstrates that regular exercise may act synergistically with diet to promote a more resilient and functionally capable microbiota.

Environmental and genetic influences

Beyond intrinsic factors, the external environment profoundly shapes the gut microbiome. Early exposure to farm animals, pets, rural environments, and less hygienic settings is associated with increased microbial diversity and reduced risk of allergies and autoimmune conditions, supporting the hygiene hypothesis (Cresci & Bawden, 2015). Conversely, urbanization, excessive sanitation, and decreased biodiversity exposure can limit microbial richness. Antibiotic overuse, particularly during infancy and childhood, significantly disrupts the microbiota, often leading to long-term compositional and functional shifts (Fouhy et al., 2019). Additionally, host genetics contribute to microbiota composition, although to a lesser extent than environmental factors.

Twin studies have shown that while genetics play a role, shared environments have a stronger influence on early-life microbiota similarity (Hill et al., 2017). Finally, as individuals age, the gut microbiota tends to destabilize again, characterized by reduced diversity and shifts in dominant bacterial groups, which correlates with frailty and age-related diseases (Salazar et al., 2014). Thus, a lifetime of interactions between genetics, environment, diet, and lifestyle continuously molds the human gut microbiome, with profound implications for health and disease.

3. The gut microbiome: core functions and systemic impact

The gut microbiome, composed of bacteria, viruses, fungi, and archaea, is often referred to as a "forgotten organ" due to its indispensable role in human health (D'Argenio & Salvatore, 2015). This complex microbial community contributes to digestion, vitamin synthesis, immune regulation, pathogen defense, and maintenance of intestinal barrier integrity. When its balance is disrupted-a state known as dysbiosis-it can lead to or exacerbate various health conditions. Notably, inflammatory bowel diseases (IBD), including Crohn’s disease and ulcerative colitis, are closely linked to dysbiosis marked by reduced levels of anti-inflammatory bacteria like *Faecalibacterium prausnitzii* and a surge in pathogenic Proteobacteria (Zheng et al., 2022). This microbial imbalance contributes to chronic intestinal inflammation and immune dysregulation.

The consequences of gut microbiota disruption extend far beyond the gastrointestinal tract. Dysbiosis has been implicated in liver diseases, cardiovascular conditions, neurodegenerative disorders, and metabolic syndromes. For instance, in liver cirrhosis, increased gut permeability and bacterial translocation along the gut-liver axis can intensify liver inflammation and fibrotic progression (Young Lee & Suk, 2020). The gut-brain axis also links microbiota composition to neurological health; as highlighted by Chen et al. (2021), imbalances in gut flora may influence neuroinflammation and cognitive function, potentially contributing to diseases like Alzheimer’s. Furthermore, alterations in microbial populations can promote metabolic disturbances such as obesity, type 2 diabetes, and non-alcoholic fatty liver disease (NAFLD), partly through increased energy harvest, systemic inflammation, and impaired glucose metabolism (Wu et al., 2021).

Beyond metabolic and neurological health, recent findings point to the gut-skin axis as another domain influenced by microbial health. Conditions such as psoriasis, acne, atopic dermatitis, and alopecia areata may be aggravated by gut dysbiosis, which promotes systemic inflammation and disrupts immune and skin barrier function (Ryguła et al., 2024). Probiotic therapies aimed at restoring microbial balance are being explored as adjunct treatments for these skin disorders. The gut microbiome also plays a critical role in modulating immune responses and defending against infections. It supports mucosal barrier integrity and helps the immune system distinguish between harmful pathogens and benign commensals. According to Wiertsema et al. (2021), dysbiosis undermines colonization resistance and impairs immune protection, thereby increasing vulnerability to both local and systemic infections.

The gut microbiome is not only a sentinel of gastrointestinal health but also a master regulator of systemic physiology, influencing everything from cognitive function and energy metabolism to skin integrity and immune resilience. Understanding and preserving its balance through targeted dietary and lifestyle interventions may hold the key to preventing and managing a wide array of chronic and acute diseases.

4. Probiotics in disease management: a multisystem therapeutic tool

Probiotics, defined as live microorganisms that provide health benefits when administered in adequate amounts, are increasingly recognized for their therapeutic potential in managing various diseases. Among the most well-supported applications of probiotics is the management of Irritable Bowel Syndrome (IBS). A comprehensive network meta-analysis by Wu et al. (2024) showed that probiotic supplementation, particularly with *Bifidobacterium* and *Lactobacillus* strains, led to significant improvements in symptoms such as abdominal pain, bloating, and irregular bowel movements—outperforming both prebiotics and synbiotics. Similarly, in elderly individuals, probiotics have been shown to improve digestion, reduce gastrointestinal infections, and enhance overall quality of life (Malaguarnera et al., 2012). Probiotics have also demonstrated promise in infectious disease management, particularly in improving eradication rates of *Helicobacter pylori* infections. Studies by Bai et al. (2022) and Zhang et al. (2015) confirmed that probiotic supplementation helped reduce side effects like antibiotic-associated diarrhea and enhanced overall treatment success, likely through pH modulation, immune support, and inhibition of *H. pylori* colonization.

The benefits of probiotics extend beyond the gut. In dermatological conditions such as atopic dermatitis (AD), a meta-analysis by Umborowati et al. (2022) demonstrated significant reductions in disease severity and improved patient quality of life following probiotic use.

Complementary findings from Gao et al. (2023) emphasized their potential to support skin health through antioxidant, anti-inflammatory, and barrier-enhancing effects, offering promise for the management of acne, eczema, and skin aging. Emerging evidence also highlights the role of the gut–brain axis in neurological health. In studies on Alzheimer's disease (AD), Naomi et al. (2021) observed that probiotics helped improve cognitive function and reduce neuroinflammation.

Key strains such as *Lactobacillus* and *Bifidobacterium* were found to increase brain-derived neurotrophic factor (BDNF) and support neurotransmitter balance, contributing to enhanced neuronal health and delayed cognitive decline. In neurodevelopmental disorders such as Autism Spectrum Disorder (ASD), early findings are also encouraging. A placebo-controlled pilot trial by Arnold et al. (2019) using the multi-strain formulation Visbiome showed significant improvement in gastrointestinal symptoms among children with ASD, though behavioral outcomes did not reach statistical significance-highlighting the need for larger, more targeted studies.

Altogether, probiotics are emerging as well-tolerated, biologically active agents with broad therapeutic reach. However, the success of probiotic therapy depends heavily on selecting the right strains, dosages, and treatment durations. Future directions should prioritize personalized approaches tailored to the individual's microbiome composition and the specific disease context to maximize clinical benefit.

5. Role of diet in shaping the microbiome in athletes.

Diet plays a pivotal role in shaping the composition, diversity, and metabolic activity of the gut microbiome in athletes, a factor increasingly recognized as integral to physical performance, recovery, and overall health.

High-Protein, Low-Fiber Diets

Athletes often adopt high-protein diets with minimal dietary fiber to support muscle synthesis and reduce gastrointestinal distress during intense exercise. However, this approach can significantly reduce microbial diversity and impair gut health. Clark and Mach (2016) reported that low intake of plant polysaccharides-a hallmark of performance-focused diets-correlates with reduced production of short-chain fatty acids (SCFAs) like butyrate, a key metabolite for gut barrier integrity and anti-inflammatory signaling. This dietary pattern may contribute to stress-induced dysbiosis and "leaky gut" in athletes, particularly those undergoing heavy endurance training. Hughes and Holscher (2021) expanded on this, showing that frequent use of protein powders and refined carbohydrates, alongside limited fiber, tends to reduce beneficial bacteria like Bifidobacterium and Akkermansia. These bacteria are essential for mucosal immunity, nutrient metabolism, and the gut-brain axis, and their depletion may lead to chronic inflammation or gastrointestinal issues common among endurance athletes

Ketogenic Diets

Ketogenic diets, while effective for reducing fat mass and supporting metabolic flexibility, have raised concerns regarding their effects on gut microbial diversity. Mancin et al. (2022), however, provided a nuanced perspective by examining a ketogenic Mediterranean diet enriched with phytoextracts (KEMEPHY) in soccer players. After 30 days, microbial diversity remained stable, and the intervention led to beneficial shifts in specific taxa: Bifidobacterium levels decreased, but butyrate-producing genera like Ruminococcus and Butyricimonas increased. These results suggest that when plant polyphenols and nutrient diversity are preserved, ketogenic diets may not harm, and may even support, microbial resilience.

Mediterranean and Polyphenol-Rich Diets

Although not the primary focus of intervention studies in the provided literature, diets rich in polyphenols, unsaturated fats, and fermentable fibers (like the traditional Mediterranean diet) have consistently been linked to enhanced gut microbial diversity and increased SCFA production. Hughes and Holscher (2021) note that emphasizing omega-3 fatty acids, varied protein sources, and prebiotic compounds contributes to improved gastrointestinal function and may reduce inflammation and oxidative stress, supporting faster recovery and better immune response in athletes.

Personalized Nutrition and Enterotype-Specific Responses

Dietary responses vary between individuals due to differences in their gut microbiome compositions, or enterotypes, as well as host genetics. Matusheski et al. (2021) emphasized that the effectiveness of fiber-rich or high-fat diets may depend on the host's baseline microbiota. For example, individuals with higher Prevotella-to-Bacteroides ratios respond more favorably to fiber interventions for weight loss and glycemic control. This inter-individual variability highlights the future potential of microbiome-based personalized nutrition for athletes, moving beyond generic dietary prescriptions to precision plans based on microbial profiling.

Rapid Microbiota Response to Short-Term Dietary Changes and exercise

The gut microbiome is remarkably dynamic and can respond to dietary changes within 24 to 48 hours. Singh et al. (2017) found that abrupt shifts to animal- or plant-based diets significantly altered microbial composition in less than two days, though these changes reversed shortly after discontinuation. For athletes who frequently travel, change routines, or experiment with new supplements or diets, this underscores the importance of maintaining microbiota-supportive foods consistently. While diet independently influences the gut microbiome, it acts synergistically with physical activity. Mohr et al. (2020) concluded that the combined effect of exercise and sport-specific diets results in increased metabolic potential of the microbiota, favoring taxa that enhance nutrient extraction, SCFA production, and anti-inflammatory capacity. These benefits likely explain why athletes often present with a more "health-associated" microbiota-characterized by high resilience, functional redundancy, and greater stability.

In conclusion, dietary strategies in athletes profoundly influence the gut microbiome. While high-protein, low-fiber diets may support short-term performance, they risk reducing microbial diversity and gut barrier function. In contrast, fiber-rich, polyphenol-dense, and microbiota-targeted diets such as ketogenic Mediterranean or personalized nutrition plans appear to balance performance goals with gut health. As research deepens, individualized dietary protocols based on microbiome composition are poised to become central to sports nutrition strategies.

6. The role of exercise on the gut microbiome

Acute exercise

Acute exercise induces significant but transient changes in the metabolic activity of the gut microbiota, rather than large shifts in its composition. In a study by Tabone et al. (2021), a single session of moderate-intensity running in cross-country athletes altered 85 serum and 12 fecal metabolites and impacted six bacterial taxa, including *Rombutsia, Blautia, Ruminiclostridium 9* and *Clostridium phoceensis*. Notably, the pathways most affected in serum included alanine, aspartate and glutamate metabolism, while in feces, tryptophan and phenylalanine biosynthesis pathways were notably altered. These findings highlight how acute exercise promotes an exchange of metabolites between gut and systemic compartments, suggesting enhanced host-microbiota crosstalk.

While acute exercise typically has limited effects on overall microbial diversity, it does result in transient changes in specific microbial taxa. Grosicki et al. (2023) observed modest but consistent changes in microbial community structure following acute bouts, with increases in bacteria capable of metabolizing lactate into short-chain fatty acids (SCFAs), particularly *Veillonella* species. Such metabolic adaptations could support recovery and performance via enhanced energy metabolism and reduced inflammation.

Intense exercise can increase intestinal permeability ("leaky gut") and provoke immune stress, potentially contributing to gastrointestinal symptoms in athletes. Clark and Mach (2016) reported that exercise-induced activation of the hypothalamic-pituitary-adrenal (HPA) axis and autonomic nervous system can alter gut barrier function and modulate microbiota composition, with downstream effects on stress hormones, cytokine production, and neurotransmitter signaling. These effects are particularly pronounced in endurance sports involving dehydration or heat stress.

The gut-derived metabolite trimethylamine N-oxide (TMAO), linked to cardiovascular risk, has been examined in relation to acute exercise. Ong et al. (2024) found that a single session of intermittent exercise did not significantly affect circulating TMAO concentrations following choline ingestion, suggesting that short-term activity does not immediately alter microbial pathways involved in TMAO production. This contrasts with long-term exercise, which may exert cardioprotective effects through chronic remodeling of microbial metabolism.

As summarized in reviews by Mohr et al. (2020) and Aya et al. (2021), acute exercise contributes to the modulation of microbial activity, including SCFA production, mucosal immunity, and energy harvest, but its effects are largely transient and depend on intensity, duration, and individual microbiome baseline. These changes may serve as precursors to the more stable adaptations seen with chronic training. Barton et al. (2017) demonstrated that long-term athletes harbor significantly higher microbial diversity and enhanced metabolic pathways than sedentary individuals, but also emphasized that even a single bout of activity can nudge microbial function in beneficial directions.

Regular exercise

Regular physical activity has emerged as a potent modulator of gut microbiota composition, exerting widespread and multifaceted effects on microbial diversity, metabolic activity, and systemic health outcomes. A comprehensive body of evidence reveals that regular excercise enhances the abundance of beneficial gut bacteria-particularly short-chain fatty acid (SCFA)-producing genera such as *Akkermansia*, *Faecalibacterium*, *Veillonella*, and *Roseburia*-which are known to support gut barrier integrity, immune modulation, and host metabolism (Pérez-Prieto et al., 2024). The mechanisms underpinning these changes involve a cascade of physiological adaptations including modulation of bile acid profiles, enhanced gut motility, and reduced intestinal permeability, all of which contribute to a more diverse and resilient gut microbiome (Zeppa et al., 2019). Notably, physical activity also acts as a hormetic stressor that strengthens gut epithelial integrity by decreasing the expression of inflammatory mediators and heat shock proteins, thereby fortifying the gut barrier (Zeppa et al., 2019).

In older adults, who are particularly vulnerable to age-associated dysbiosis and chronic inflammation, regular exercise has been shown to reduce the abundance of pro-inflammatory taxa like *Proteobacteria* while promoting health-supporting genera such as *Bifidobacterium* and *Lactobacillus*, potentially reversing detrimental microbial shifts associated with aging (Ramos et al., 2022). Moreover, the exercise-induced microbial shifts have been correlated with favorable changes in host physiological parameters, including improved insulin sensitivity, lipid metabolism, and reduced systemic inflammation (Campaniello et al., 2022).

The dynamic interplay between regular exercise and the gut microbiota also extends to the gut-brain axis, where exercise-driven enhancement of SCFA-producing microbes is linked to reduced anxiety, improved cognitive function, and enhanced mood regulation via vagal and neuroendocrine signaling pathways (Dalton et al., 2018). Even among cardiovascular patients, physical activity has been shown to influence microbial-mediated pathways that modulate inflammation, highlighting its potential as a non-pharmacological tool for systemic disease management (Fernandez et al., 2018).

Despite the strong observational and interventional evidence, heterogeneity in methodologies-ranging from exercise modalities to microbiome profiling techniques-presents challenges in identifying universal microbial signatures of physical activity (Pérez-Prieto et al., 2024). Nonetheless, the overarching consensus supports physical activity as a critical lifestyle intervention capable of reshaping the gut microbiome toward a compositionally and functionally favorable state across the lifespan.

7. Use of probiotics in improving performance in athletes

Probiotic supplementation has attracted growing interest as a novel strategy to enhance athletic performance, primarily by modulating the gut microbiota and its systemic interactions with metabolism, immunity, and recovery physiology. Recent clinical research has begun to uncover measurable benefits in endurance and strength outcomes, as well as reductions in inflammation and gastrointestinal distress. For instance, Przewłócka et al. (2023) demonstrated that supplementation with probiotics combined with vitamin D3 significantly enhanced aerobic capacity in mixed martial arts athletes, as evidenced by increased time-to-exhaustion and reductions in intestinal inflammation and permeability.

These outcomes suggest that probiotics may play a critical role in preserving gut barrier integrity during intense physical stress, thereby supporting better energy utilization and reducing exercise-induced fatigue. This is consistent with findings from Huang et al. (2019), who showed that six weeks of *Lactobacillus plantarum* TWK10 administration in healthy individuals led to dose-dependent improvements in VO_2max and exercise endurance, along with favorable changes in body composition, including reduced fat mass and increased lean muscle mass.

Beyond endurance, probiotics appear to support muscle maintenance and recovery, likely through gut-derived metabolic signaling. Gut microbes produce short-chain fatty acids (SCFAs) such as butyrate and propionate, which influence energy regulation, insulin sensitivity, and muscle protein synthesis. As reviewed by Giron et al. (2022), these metabolites also modulate systemic inflammation and oxidative stress-two critical factors affecting muscle repair and fatigue. Such mechanisms are especially relevant for athletes undergoing prolonged or high-intensity training, where maintaining muscle function and minimizing recovery time are performance-critical. These microbial effects align with the conclusions drawn by Díaz-Jiménez et al. (2021), who found in their systematic review that while probiotics did not always yield direct gains in performance metrics, they consistently reduced upper respiratory tract infections, improved gastrointestinal comfort, and enhanced antioxidant capacity-all of which help maintain training continuity and mitigate performance decline due to illness or inflammation.

Recognition of these benefits has led to their formal endorsement in sport nutrition guidelines. Jäger et al. (2019), in their position stand for the International Society of Sports Nutrition, highlighted the role of specific probiotic strains in reducing exercise-related illness, improving protein absorption, and maintaining gut mucosal integrity during environmental and physical stress. This perspective is echoed by Vitale and Getzin (2019), who recommend probiotic use for endurance athletes particularly susceptible to gastrointestinal disturbances and immune suppression. These converging lines of evidence suggest that while probiotics may not be direct ergogenic aids in the traditional sense, their ability to enhance physiological resilience, recovery efficiency, and immune balance makes them valuable components of a comprehensive performance nutrition plan. Further research focusing on strain specificity, dosage, and individualized responses will be essential to refine their application in elite sports contexts.

8. **Conclusion**:

The gut microbiome exerts a profound influence on host physiology, extending well beyond gastrointestinal functions to encompass immune regulation, metabolic homeostasis, neurocognitive processes, and systemic resilience. Its composition and functional capacity are shaped by a complex interplay of intrinsic and extrinsic factors, among which diet, physical activity, and probiotic interventions are particularly modifiable and clinically relevant. Evidence indicates that dietary patterns enriched in fermentable fibers and polyphenols promote microbial diversity and metabolic output, while structured physical activity induces compositional shifts favoring short-chain fatty acid-producing taxa and enhancing gut barrier function and immune modulation. Probiotic supplementation further contributes to microbiome modulation, demonstrating efficacy in ameliorating dysbiosis and supporting host adaptation to physiological stress, particularly in athletic populations.

Importantly, these lifestyle interventions exhibit synergistic effects, collectively contributing to the maintenance of a resilient and health-promoting microbiota. As our understanding of host-microbiome interactions deepens, future research should prioritize the development of personalized, evidence-based protocols that integrate dietary, physical, and microbial strategies to optimize microbiome composition and function, thereby advancing preventive health and performance outcomes..

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Authors' contribution

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Methodology: GŁ,
Software: KD, MB
Check: JM, JZ
Formal analysis: GŁ, KD
Investigation: Resources: MM, MB
Data curation: KM, JK
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