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Physical Activity and Gut Microbiota: Implications for Metabolic Health - A Narrative Review

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ABSTRACT

Background. The gut microbiota plays a key role in metabolic regulation and is increasingly recognized as a mediator of lifestyle-related health outcomes. Physical activity has emerged as a potential modulator of microbial composition and function.

Aim. This narrative review aims to summarize current evidence on the relationship between physical activity and the gut microbiota and to evaluate its implications for metabolic health.

Materials and Methods. A PubMed search of English-language studies published over the last 10 years was conducted to assess the effects of physical activity on the gut microbiota and metabolic health. Additional studies were identified through reference screening.

Results. Regular moderate physical activity is associated with increased microbial diversity and a higher abundance of beneficial bacteria, including short-chain fatty acid producers. These changes are linked to improved glucose metabolism, reduced inflammation, and enhanced intestinal barrier function. However, excessive or prolonged high-intensity exercise may induce adverse effects, such as increased gut permeability and dysbiosis. The observed effects are strongly influenced by diet and individual factors.

Conclusions. The gut microbiota represents an important mediator of exercise-induced metabolic adaptations. Combined lifestyle interventions, particularly physical activity and a fiber-rich diet, may provide synergistic benefits. Further research is needed to develop personalized strategies targeting the gut microbiota in metabolic disease prevention.

Keywords: physical activity, gut microbiota, metabolic health, exercise, dysbiosis, short-chain fatty acids, insulin sensitivity, inflammation

1. Introduction

The gut microbiota is a complex and dynamic ecosystem of microorganisms that plays a crucial role in maintaining host homeostasis by participating in metabolic regulation, immune responses, and preservation of intestinal barrier integrity [2,13]. Growing evidence indicates that both the composition and metabolic activity of the gut microbiota are closely associated with the development of chronic diseases, including obesity, type 2 diabetes, and cardiovascular disorders [2,5]. Disturbances in microbial balance, commonly referred to as dysbiosis, have been linked to enhanced inflammation, metabolic dysfunction, and deterioration of overall health status [3,9].

Among the most important modulators of the gut microbiota are lifestyle-related factors, particularly diet and physical activity [4,5]. The contemporary dietary model, characteristic of many developed countries, is typically marked by low fiber intake and high consumption of ultra-processed foods, which may contribute to unfavorable alterations in gut microbial composition and an increased risk of metabolic disturbances [1,5]. Dietary fiber, which serves as a major substrate for gut bacteria, plays a central role in the production of short-chain fatty acids (SCFAs), metabolites involved in glucose and lipid metabolism as well as inflammatory regulation [1,5].

At the same time, growing attention has been directed toward the impact of physical activity on the gut microbiota. Current evidence suggests that regular moderate exercise may promote greater microbial diversity and increase the abundance of bacteria with beneficial metabolic potential, including SCFA-producing taxa [2,3,9]. These alterations may contribute to improved insulin sensitivity, reduced inflammation, and better regulation of energy metabolism [5,15]. However, the relationship between physical activity and the gut microbiota is complex and appears to depend on multiple factors, such as exercise intensity, duration, dietary habits, and baseline metabolic status [4,8,21].

An important aspect of this relationship is its bidirectional nature. On the one hand, physical exercise can modify the composition and function of the gut microbiota. On the other hand, gut microorganisms, through the production of metabolites and signaling molecules, may influence physical performance, exercise adaptation, and skeletal muscle function [7,9,12]. The concepts of the gut-muscle axis and the gut-brain axis emphasize the role of the gut microbiota as an integrator of metabolic, immune, and neuroendocrine signals [6,12].

Despite the growing number of studies, important gaps remain in our understanding of the mechanisms underlying the interactions between physical activity and the gut microbiota. Findings are often inconsistent due to heterogeneity of study populations, differences in exercise protocols, and difficulties in separating the effects of diet from those of exercise itself [4,8,19]. In particular, it remains necessary to determine the optimal type, intensity, and duration of physical activity that may promote beneficial microbial changes and improve metabolic health.

The aim of this narrative review is to present the current state of knowledge on the effects of physical activity on the gut microbiota and to discuss the significance of these relationships in the context of metabolic health. Particular attention is given to biological mechanisms, interactions with diet, and potential clinical and practical implications.

2. Gut Microbiota and Metabolic Health

2.1. Composition and Functions of the Gut Microbiota

The gut microbiota is a complex and dynamic ecosystem of microorganisms that plays a fundamental role in maintaining host homeostasis. It comprises trillions of bacteria, viruses, fungi, and archaea whose collective genetic potential far exceeds that of the human genome, thereby providing extensive metabolic and regulatory capabilities [3,4]. The dominant bacterial phyla in the human intestine are Firmicutes and Bacteroidetes, and their relative abundance as well as functional activity are closely associated with health status [4,21].

The gut microbiota is involved in numerous essential physiological processes, including nutrient digestion, vitamin synthesis, regulation of immune function, and maintenance of intestinal barrier integrity [2,13]. In addition, gut microbial diversity has been associated with physical fitness and overall metabolic health, suggesting that the microbiota may represent an important link between lifestyle factors and systemic physiological function [22,23].

2.2. Microbial Metabolites and Metabolic Regulation

One of the most important functions of the gut microbiota is the production of metabolites, particularly short-chain fatty acids (SCFAs), including butyrate, propionate, and acetate, which are generated through the fermentation of indigestible dietary components, mainly fiber [1,5]. SCFAs play an important role in the regulation of glucose and lipid metabolism, influence insulin sensitivity, modulate immune responses, and exert anti-inflammatory effects [1,5,9].

Gut microorganisms also contribute to host energy homeostasis by regulating energy extraction from the diet and influencing the secretion of gut-derived hormones such as glucagon-like peptide-1 (GLP-1) and peptide YY (PYY) [1]. Through these mechanisms, microbial metabolites act as important mediators between diet, intestinal physiology, and metabolic regulation.

2.3. Dysbiosis and Metabolic Disorders

Disturbances in the balance of the gut microbiota, referred to as dysbiosis, have been linked to the development of numerous metabolic disorders, including obesity, insulin resistance, type 2 diabetes, and cardiovascular disease [2,5,9]. Dysbiosis may contribute to increased intestinal permeability, allowing lipopolysaccharides (LPS) to translocate into the circulation and trigger so-called metabolic endotoxemia, which promotes chronic low-grade inflammation [5,15].

This persistent low-grade inflammatory state is considered one of the key mechanisms linking alterations in gut microbial composition with metabolic dysfunction [9,29]. Accordingly, an imbalance in the gut microbiota may not only reflect impaired metabolic health but may also actively contribute to disease progression.

2.4. The Gut Microbiota as a Systemic Regulator

Beyond its local effects within the gastrointestinal tract, the gut microbiota also modulates the gut-brain axis and the gut-muscle axis, thereby influencing neuroendocrine function, inflammatory status, and muscle metabolism [6,12]. Importantly, the relevance of the gut microbiota extends beyond its taxonomic composition and includes its functional capacity and metabolic activity [4].

An increasing number of studies suggest that the ability of microorganisms to produce specific metabolites and regulate biological pathways may be more important for health than the mere presence or absence of particular bacterial species [4]. The complexity of interactions between the gut microbiota and the host makes its role in metabolic health multifaceted and dependent on numerous factors, including diet, lifestyle, age, and the physiological condition of the individual [2,5,21].

3. Diet and Gut Microbiota

3.1. Diet as a Determinant of Gut Microbiota Composition

Diet is one of the most important factors determining the composition and function of the gut microbiota. The contemporary dietary model, commonly referred to as the Western diet, is characterized by a high intake of ultra-processed foods, simple sugars, and saturated fats, along with a low consumption of dietary fiber [1,5]. Such dietary patterns are associated with reduced microbial diversity and the proliferation of bacteria with pro-inflammatory potential, which may contribute to dysbiosis and the development of metabolic disorders [5].

In contrast, diets rich in plant-based foods, including vegetables, fruits, and whole grains, are associated with increased microbial diversity and a greater abundance of bacteria considered beneficial to health [5]. The gut microbiota exhibits considerable plasticity and can respond rapidly to dietary changes, highlighting the importance of daily eating habits in shaping its composition and function [3].

3.2. Role of Dietary Fiber and Microbial Metabolites

Dietary fiber plays a key role in shaping the gut microbiota and its metabolic activity. It serves as the primary energy source for gut bacteria, which ferment indigestible carbohydrates to produce short-chain fatty acids (SCFAs), such as butyrate, propionate, and acetate [1,5]. These metabolites exert important biological effects, including the regulation of glucose and lipid metabolism, appetite control, and anti-inflammatory activity [1,5].

SCFAs also contribute to maintaining intestinal barrier integrity and modulating immune responses. Additionally, they influence the secretion of gut hormones such as glucagon-like peptide-1 (GLP-1) and peptide YY (PYY), thereby improving insulin sensitivity and supporting body weight regulation [1]. It should be emphasized, however, that the mechanisms of action of dietary fiber are complex and extend beyond SCFA production, suggesting the involvement of additional regulatory pathways [1].

3.3. Dietary Patterns and Metabolic Health

Different dietary patterns exert distinct effects on the gut microbiota and metabolic health. The Mediterranean diet, rich in fiber, polyphenols, and unsaturated fatty acids, promotes the growth of SCFA-producing bacteria and is associated with a lower risk of metabolic and cardiovascular diseases [5,29]. Similarly, plant-based diets support fiber-fermenting bacteria and enhance the production of beneficial microbial metabolites.

In contrast, high-fat, low-fiber diets promote the growth of pro-inflammatory bacteria, increase intestinal permeability, and contribute to systemic inflammation [5]. Importantly, the effects of diet on the gut microbiota are often dependent on long-term dietary habits and interactions with other lifestyle factors, such as physical activity [5].

Furthermore, different dietary patterns may influence not only the composition of the gut microbiota but also physical performance and exercise capacity. Diets rich in fiber and bioactive compounds, such as the Mediterranean and plant-based diets, support the development of beneficial microbial communities, whereas high-protein diets with insufficient fiber intake may lead to unfavorable alterations in the gut microbiota [14].

4. Physical Activity as a Modulator of the Gut Microbiota

Physical activity is one of the key lifestyle factors influencing the composition and function of the gut microbiota. Numerous studies indicate that physically active individuals, including athletes, exhibit greater microbial diversity and a higher abundance of bacteria with beneficial metabolic potential compared with sedentary individuals [8,13,21]. These changes include an increased presence of short-chain fatty acid (SCFA)-producing bacteria, such as

Faecalibacterium, *Roseburia*, and *Akkermansia*, which play a crucial role in maintaining intestinal barrier integrity, regulating inflammatory processes, and modulating glucose and lipid metabolism [2,5,9].

Importantly, the effects of physical activity are not limited to changes in microbial composition but also extend to the functional capacity of the microbiota, including its ability to produce bioactive metabolites [4]. The gut microbiota may therefore act as an important intermediary between diet, physical activity, and physical performance, influencing metabolism, immune responses, and recovery processes [14]. Moreover, the relationship between physical activity and the gut microbiota is bidirectional: while regular exercise can modify microbial composition and function, the microbiota itself may influence exercise capacity and physiological adaptation to training [30].

The mechanisms underlying these interactions are complex and multifactorial. Physical activity may influence the gut microbiota through several pathways, including reduced intestinal transit time, modulation of immune function (e.g., increased immunoglobulin A secretion and altered cytokine profiles), and changes in bile acid metabolism, as well as activation of metabolic signaling pathways such as AMP-activated protein kinase (AMPK) [2,5,9]. A key role is also attributed to the reduction of circulating lipopolysaccharides (LPS) and associated metabolic endotoxemia, which contributes to decreased chronic low-grade inflammation [5,15].

Additionally, increasing attention has been given to the gut-muscle axis, in which the gut microbiota and skeletal muscle communicate through microbial metabolites and myokines, thereby influencing energy metabolism and overall physiological function [12]. The gut microbiota may also play an important role in exercise adaptation and musculoskeletal health, further emphasizing the significance of physical activity as a modulator of microbial composition and function [25].

However, the effects of physical activity on the gut microbiota are not uniform and depend largely on the intensity and type of exercise. Regular moderate physical activity is consistently associated with beneficial changes, including increased microbial diversity, a higher abundance of SCFA-producing bacteria, and improved intestinal barrier function [2,3,9]. In contrast, very intense and prolonged exercise, particularly in endurance sports, may lead to adverse effects such as increased intestinal permeability (“leaky gut”), enhanced inflammatory responses, and microbial imbalance [17,31]. This suggests a U-shaped relationship, in which moderate levels of physical activity provide the greatest health benefits, whereas excessive training may become detrimental [9].

Training interventions, such as combined high-intensity interval training (HIIT) and resistance training, have been shown to induce significant changes in gut microbiota composition alongside improvements in body composition and physical performance [28].

An important consideration is that exercise-induced changes in the gut microbiota may be transient and can revert after the cessation of regular physical activity [18,26]. Furthermore, the microbial response to exercise is strongly influenced by coexisting factors, including diet, body composition, age, and training status [4,8,21]. In particular, dietary factors-especially fiber intake-play a crucial role, as they provide the primary substrate for gut bacteria and may potentiate the beneficial effects of physical activity [5].

Therefore, the impact of exercise on the gut microbiota should not be considered in isolation but rather as part of a broader lifestyle context involving diet and other behavioral factors.

5. Metabolic Implications of Exercise-Induced Changes in the Gut Microbiota

Exercise-induced alterations in the gut microbiota may translate into significant metabolic benefits, including improved body weight regulation, enhanced glucose metabolism, and reduced chronic inflammation. Increasing evidence suggests that the gut microbiota acts as an important intermediary linking physical activity with metabolic health outcomes [5,9].

Microbial metabolites, particularly short-chain fatty acids (SCFAs), may serve as an additional energy source and play a key role in the regulation of glucose and lipid metabolism, thereby supporting skeletal muscle function and overall exercise performance [20]. A favorable gut microbiota profile may also enhance physical performance through improved energy metabolism, modulation of inflammatory processes, and maintenance of immune function and intestinal barrier integrity [30].

5.1. Body Composition and Obesity

Physical activity is a key determinant of body composition, and its effects may be partially mediated by the gut microbiota. Intervention studies have shown that structured exercise programs lead to reductions in body weight, decreases in fat mass, and improvements in metabolic parameters, accompanied by changes in gut microbial composition [10,11].

In particular, modifications in the abundance of bacteria associated with energy metabolism have been observed, as well as alterations in the Firmicutes-to-Bacteroidetes ratio, which has been linked to obesity [10].

Importantly, the response of the gut microbiota to physical activity appears to depend on the baseline metabolic status of the individual. In lean individuals, changes in microbial composition and SCFA production are often more pronounced and more strongly associated with improvements in body composition than in individuals with overweight or obesity [18,24]. This suggests that the gut microbiota may play a role in the interindividual variability of responses to exercise interventions.

5.2. Insulin Resistance and Glucose Metabolism

Exercise-induced changes in the gut microbiota are also associated with improved insulin sensitivity and regulation of glucose metabolism. Studies conducted in individuals with insulin resistance, prediabetes, and type 2 diabetes have demonstrated that exercise interventions can reduce inflammatory markers and metabolic endotoxemia, leading to improved metabolic function [15].

Systematic reviews indicate that physical activity may increase the abundance of bacteria with beneficial metabolic properties, such as *Bifidobacteriaceae*, *Akkermansia*, and *Bacteroides*, while reducing the proportion of pro-inflammatory taxa [27].

These microbial changes are associated with improvements in key metabolic parameters, including fasting glucose levels, glycated hemoglobin (HbA1c), and insulin resistance indices such as HOMA-IR, highlighting the important role of the gut microbiota in glucose homeostasis.

5.3. Inflammation and Gut Barrier Function

Chronic low-grade inflammation is a central mechanism underlying the development of metabolic diseases, and the gut microbiota plays a significant role in its regulation. Evidence suggests that physical activity may reduce levels of inflammatory markers and decrease metabolic endotoxemia, which is associated with beneficial shifts in gut microbial composition [5,15].

These changes are also linked to improvements in intestinal barrier function. Reduced gut permeability and decreased translocation of lipopolysaccharides (LPS) into the bloodstream may attenuate systemic inflammatory responses and support metabolic homeostasis [9].

However, it should be noted that these effects depend on exercise intensity. While moderate physical activity exerts anti-inflammatory effects, excessive or prolonged training may have the opposite impact, promoting inflammation and impairing gut barrier integrity [17,31].

5.4. Cardiometabolic Risk Factors

Exercise-induced changes in the gut microbiota may also influence cardiovascular risk factors. Studies indicate that lifestyle interventions incorporating physical activity-particularly when combined with a Mediterranean diet-lead to improvements in lipid profiles, including reductions in triglyceride levels and increases in high-density lipoprotein (HDL) cholesterol [10].

Moreover, alterations in the gut microbiota and intestinal metabolome, including pathways related to bile acids and lipid metabolism, have been associated with improvements in cardiometabolic parameters [11]. These findings suggest that the gut microbiota may represent one of the mechanisms through which physical activity reduces the risk of cardiovascular disease.

6. Mechanisms Linking Physical Activity, Gut Microbiota, and Metabolic Health

The interactions between physical activity, the gut microbiota, and metabolic health are mediated by a range of complex mechanisms involving metabolic, immunological, and neuroendocrine pathways. One of the key components of these interactions is the production of short-chain fatty acids (SCFAs), such as butyrate, propionate, and acetate, which are generated through the fermentation of dietary substrates by gut bacteria. SCFAs play a central role in the regulation of glucose and lipid metabolism, improvement of insulin sensitivity, and modulation of inflammatory responses, making them highly relevant in the context of metabolic diseases [1,5,9].

Another important mechanism involves the role of the gut microbiota in maintaining intestinal barrier integrity. A well-balanced microbiota supports epithelial tight junctions and produces metabolites with protective effects on the intestinal lining. In contrast, microbial imbalance may lead to increased intestinal permeability, allowing lipopolysaccharides (LPS) to enter the circulation and induce metabolic endotoxemia and chronic low-grade inflammation [5,15]. Physical activity, particularly at moderate intensity, may counteract these processes by improving gut barrier function and reducing inflammation.

Modulation of the immune system represents another key pathway linking physical activity and the gut microbiota. The gut microbiota influences the development and function of immune cells, as well as the balance between pro- and anti-inflammatory cytokines. Regular physical activity has been shown to enhance these processes by reducing pro-inflammatory cytokine levels and promoting anti-inflammatory mechanisms, thereby supporting metabolic homeostasis [2,9].

Increasing attention has also been given to the gut-brain axis and the gut–muscle axis. Gut microorganisms produce metabolites and neuroactive compounds that may influence central nervous system function, appetite regulation, and physical activity behavior. At the same time, physical activity affects the gut microbiota through hormonal and metabolic changes, creating a bidirectional communication system. Within the gut-muscle axis, the microbiota may influence skeletal muscle metabolism, function, and adaptation to exercise through interactions involving microbial metabolites and myokines [6,12].

In addition, the gut microbiota is involved in the regulation of bile acid metabolism and the expression of genes related to energy homeostasis, including pathways such as AMP-activated protein kinase (AMPK). These mechanisms may influence substrate utilization, glucose homeostasis, and lipolysis, further highlighting the role of the microbiota as a mediator of exercise-induced metabolic adaptations.

The complexity of these mechanisms indicates that the gut microbiota is not merely a passive component of the gastrointestinal system, but rather an active regulator of metabolic processes that mediates the effects of both physical activity and diet.

7. Discussion

The available evidence indicates that physical activity, diet, and the gut microbiota are closely interconnected and collectively play a crucial role in metabolic health. The gut microbiota appears to function as an intermediary between lifestyle factors and physiological processes, influencing metabolism, inflammatory status, and intestinal barrier integrity [5,9]. At the same time, both physical activity and dietary habits shape the composition and metabolic potential of the gut microbiota, highlighting its role as an integrative component of lifestyle-related health regulation [4,5].

One of the most consistent findings emerging from the literature is that the beneficial effects of physical activity on the gut microbiota are most pronounced in the context of regular, moderate exercise. Such activity is associated with increased microbial diversity and a higher abundance of short-chain fatty acid (SCFA)-producing bacteria, which may contribute to improvements in metabolic parameters [2,3,9]. In contrast, excessive or prolonged high-intensity exercise may lead to adverse outcomes, including increased intestinal permeability, enhanced inflammation, and dysbiosis [17,31]. These observations suggest a non-linear, U-shaped relationship, in which both insufficient and excessive levels of physical activity may be detrimental. Furthermore, the response to exercise may be partially determined by the baseline composition of the gut microbiota, indicating the potential for personalized approaches to exercise interventions [28].

Another important consideration is the strong interaction between diet and the effects of physical activity on the gut microbiota. Current evidence suggests that physical activity alone may not be sufficient to induce favorable microbial changes without an appropriate dietary context, particularly one rich in dietary fiber [5]. Diet provides the primary substrates for gut bacteria, and its composition may either enhance or attenuate the effects of exercise. Therefore, the gut microbiota should be viewed as a central mediator integrating multiple lifestyle factors rather than as an isolated component.

A further challenge lies in the substantial interindividual variability in microbial responses to physical activity. Research indicates that these responses are influenced by factors such as body composition, age, training status, and baseline metabolic condition [4,8,21]. For instance, lean individuals often exhibit more pronounced microbiota changes than individuals with obesity, possibly due to pre-existing metabolic disturbances and chronic low-grade inflammation. Moreover, some exercise-induced changes in the gut microbiota appear to be transient and may diminish after cessation of training, emphasizing the importance of long-term adherence to physical activity [18,26].

Emerging evidence also suggests that the gut microbiota may influence motivation and behavior related to physical activity through interactions with the gut-brain axis and reward systems [16]. This bidirectional relationship highlights the potential role of the microbiota not only as a mediator of physiological adaptation but also as a factor influencing behavioral patterns associated with exercise.

Despite the growing body of research, several important limitations must be acknowledged. Many studies are characterized by small sample sizes, short intervention periods, and a lack of standardization in dietary control and exercise protocols [4,19]. In addition, it remains challenging to isolate the independent effects of physical activity from other lifestyle factors, which complicates the identification of causal relationships. Future research should focus on well-designed, long-term studies incorporating advanced analytical approaches, such as metagenomics and metabolomics, to better understand the functional significance of microbiota alterations.

Overall, the gut microbiota represents a key link between physical activity, diet, and metabolic health. Its modulation may serve as a promising target for interventions aimed at the prevention and management of metabolic disorders.

8. Conclusions

The gut microbiota plays a central role in the regulation of metabolic health, acting as a key link between diet, physical activity, and overall physiological function. Regular moderate physical activity promotes increased microbial diversity and supports beneficial changes in both the composition and functional capacity of the gut microbiota, which may contribute to improved metabolic regulation and reduced systemic inflammation.

The interactions between physical activity, diet, and the gut microbiota are complex and multifactorial, and are influenced by individual characteristics such as metabolic status, training level, and baseline microbial composition. Diet remains a critical determinant, as it provides essential substrates for gut microorganisms and may enhance or limit the beneficial effects of exercise.

Emerging evidence suggests that the functional potential of the gut microbiota-particularly its ability to produce bioactive metabolites-may be more relevant to health outcomes than its taxonomic composition alone. A deeper understanding of these mechanisms may facilitate the development of personalized strategies based on microbiota modulation, supporting the prevention and management of metabolic disorders as well as the improvement of overall health and physical performance.

Disclossure

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