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The Impact of the Human Microbiome on Gut Health: Recent Research

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Abstract In this study, the composition and diversity of the intestinal microbiome and its interaction with the host are discussed in depth, and the key role of the microbiome in maintaining intestinal balance, promoting nutrient absorption, and preventing and treating intestinal diseases is revealed. It also introduces the current hot areas of microbiome research, including the relationship between microbiome and chronic diseases, drug response, and the development and application prospects of microbiome regulation methods. These findings provide an important basis for further understanding of the physiological functions and regulatory mechanisms of the gut microbiome, as well as the development of microbiome based intestinal health intervention strategies.

Keywords Body microbiome; Intestinal health; Intestinal microbial balance; Intestinal disease

In recent years, with the development of high-throughput sequencing technology and the advancement of bioinformatics methods, the study of human microbiome has become a research hotspot in the field of life sciences. The human microbiome is not only closely related to human health, but also plays an important role in the occurrence and development of diseases. Therefore, in-depth exploration of the impact of the human microbiome on intestinal health is of great significance for understanding the nature of human health and disease, and for developing new disease diagnosis and treatment strategies (Hills et al., 2019).

The importance of the human microbiome is reflected in the fact that the human microbiome plays an important role in maintaining normal physiological functions of the human body, such as promoting the digestion and absorption of nutrients and participating in the synthesis of vitamins (Conlon and Bird, 2014); the human microbiome interacts with the human immune system to jointly resist the invasion of foreign pathogens; the imbalance of the human microbiome is closely related to the occurrence and development of various diseases, such as intestinal inflammation, metabolic diseases, and autoimmunity Diseases, etc. In-depth study of the human microbiome is important for understanding the nature of human health and disease.

The intestine is the largest microbial habitat in the human body, and the intestinal microbiome is an important component of the human microbiome. The relationship between the gut microbiome and gut health is close and complex (Bäumler and Sperandio, 2016). On the one hand, the intestinal microbiome promotes intestinal health by participating in the digestion and absorption of nutrients, synthesizing vitamins, secreting short-chain fatty acids, etc.; on the other hand, the intestinal microbiome interacts with the intestinal immune system to jointly resist foreign pathogens invasion and maintain intestinal homeostasis. The imbalance of the intestinal microbiome is closely related to the occurrence and development of various intestinal diseases, such as inflammatory bowel disease, irritable bowel syndrome, colon cancer, etc. In-depth exploration of the relationship between the intestinal microbiome and intestinal health is of great significance for understanding the pathogenesis of intestinal diseases and developing novel disease diagnosis and treatment strategies.

This study aims to deeply explore the impact and mechanism of the human microbiome on intestinal health. By analyzing the composition, structure, function and interaction between the intestinal microbiome and the host, it reveals the role of the intestinal microbiome in maintaining intestinal homeostasis. It plays a role in improving digestion and absorption of nutrients, regulating intestinal immunity, etc. This study will also focus on the relationship between intestinal microbiome imbalance and intestinal diseases, with a view to discovering new disease markers and therapeutic targets, and providing new ideas and methods for the diagnosis and treatment of intestinal diseases.

1 Overview of the Human Microbiome

1.1 Composition and diversity of human microbiome

The human microbiome is a complex ecosystem composed of trillions of microbial cells, which far exceed the number of cells in the human body itself (Hills et al., 2019). These microorganisms include bacteria, viruses, fungi, archaea, etc. They are widely and complexly distributed in the human body, ranging from the skin, mouth to intestines and other parts of the body. The types and quantities of these microorganisms vary significantly between different parts and individuals, and this variability constitutes the diversity of the human microbiome.

Gupta et al. (2017) explored the variation in human microbial composition and diversity among different geographical locations, ethnic groups, or lifestyles, providing a global perspective on factors influencing health and disease. The diversity of the human microbiome is not only reflected in species composition, but also in genetic composition. The microorganisms in the microbiome carry a large amount of genetic information, which constitutes the gene pool of the microbiome.

Rothschild et al. (2018) showed that environmental factors play a more important role in shaping the human intestinal microbiome than host genetic factors, emphasizing the importance of diet and lifestyle in maintaining intestinal health. The number of genes in the human microbiome far exceeds the number of genes in the human body itself. These genes play an important role in human metabolism, immunity, nutrition and other aspects.

Cai et al. (2020) research showed that there are significant differences in the types and quantities of human MSM in different organs or parts. The intestines are colonized by more than 1 000 species of microorganisms. Among the six phyla of intestinal commensal bacteria, Firmicutes and Bacteroidetes account for 90% of the total number of intestinal commensal bacteria. Most of the obligate anaerobes include The genera *Bacteroidetes*, *Clostridium*, *Faecalibacterium*, *Eubacterium*, *Ruminococcus*, *Peptococcus*, *Peptostreptococcus* and *Bifidobacterium* are also colonized by bacteria of the genera *Escherichia* and *Lactobacillus*.

1.2 Interactions between the microbiome and the host

The interaction between the microbiome and the host is a two-way process, with both the influence of microorganisms on the host and the influence of the host on the microorganisms. The microbiome helps the host digest food, synthesize vitamins, etc. by participating in the host's metabolic process. The microbiome participates in the host's metabolic process, not only helping the host digest food, but also participating in the production of short-chain fatty acids (such as butyric acid , propionic acid, and acetic acid). These substances play an important role in maintaining the integrity of the intestinal wall, regulating immune responses, and affecting the host's energy balance (Belkaid and Hand, 2014).

Selber-Hnatiw et al. (2017) examined the relationship between the microbiome and host health from the perspective of microbial community dynamics. Research highlights how microbial populations communicate with their hosts through biochemical signals, coordinating nutrient exchange and appropriate immune function. This study reveals that imbalances (dysbiosis) in microbial composition are often associated with human disease, suggesting that balanced microbial communities are critical to human health.

Milani et al. (2017) collected information and reviewed the literature and found that the composition, activity and impact of the infant intestinal microbiome on health, as well as how microorganisms colonize the neonatal intestine immediately after birth, and interact with specific compounds in human milk interactions regulate their development. The host provides the environment and nutrients for the microbiome to survive, and the host's immune system also regulates and eliminates the microbiome.

Hua et al. (2015) found that environmental factors and host genetics may interact to affect the composition of the human microbiome. The identification of host genetic variation related to the composition of the human microbiome not only provides clues for characterizing microbiome variation, but also helps to elucidate genetic Correlate biological mechanisms, prioritize genetic variants, and improve genetic risk prediction.

1.3 Distribution and function of microbiome in human body

In the intestine, the microbiome promotes intestinal health by participating in the digestion and absorption of nutrients, synthesizing vitamins, and secreting short-chain fatty acids. The gut microbiome also interacts with the intestinal immune system to defend against invasion by foreign pathogens. In the skin and oral cavity, the microbiome also plays a similar role. They maintain the health of the skin and oral cavity through interactions with host cells (Hills et al., 2019).

Popkes and Valenzano (2020) explored how interactions between the microbiome and the host influence aging dynamics. The study highlighted the association of microbial diversity with health and youthful status, with low individual microbial diversity and greater inter-individual microbial diversity. Differences are related to aging and disease states. The study highlights that the maintenance of the host-microbe symbiont (holobiont) is critical to resist external perturbations and influence host-specific aging-related phenotypes.

Milani et al. (2017) study discussed the early colonizers of the infant intestinal microbiota, its composition, activities, and effects on health. The distribution of the microbiome in the human body is extensive and complex, ranging from the skin, mouth to intestines and other parts of the body. Microbiomes in different parts of the body vary in composition and function, but overall, the microbiome plays a variety of important roles in the human body.

2 Gut Microbiome and Gut Health

The intestinal microbiome, as the largest microbial habitat in the human body, has a close and complex relationship with intestinal health. The intestinal microbiome not only participates in the digestion and absorption of nutrients, but also affects the immune function of the intestine and plays a key role in maintaining intestinal homeostasis (Figure 1). The impact of the gut microbiome on gut health will be explored in detail below.

The gut microbiome plays a crucial role in maintaining intestinal barrier function and intestinal homeostasis. By competitively excluding pathogenic microorganisms, regulating the barrier function of intestinal epithelial cells, and producing beneficial metabolites, the intestinal microbiome helps prevent the transmembrane transport of harmful substances and microorganisms and maintain the stability of the intestinal environment (Clemente et al., 2012). The intestinal microbiome has an important impact on intestinal health. Through in-depth study of the relationship between the intestinal microbiome and intestinal health, we can better understand the pathogenesis of intestinal diseases and provide new methods for the prevention and treatment of intestinal diseases. ideas and methods.

2.1 The impact of intestinal microbiome on intestinal physiological functions

The gut microbiome promotes intestinal health by participating in the digestion and absorption of nutrients. They break down dietary fiber and other difficult-to-digest carbohydrates to produce short-chain fatty acids (such as acetic acid, propionic acid, and butyric acid). These short-chain fatty acids not only provide energy for intestinal cells but also help maintain intestinal pH. Stable, promotes the growth of beneficial bacteria and inhibits the reproduction of harmful bacteria.

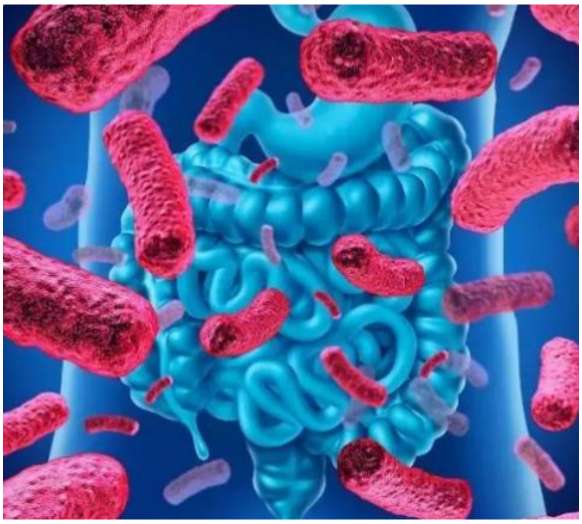

Figure 1 Enteric microorganisms

Thaiss et al. (2016) showed that intestinal microorganisms can also directly affect the function of immune cells and reduce inflammatory responses by producing metabolites such as anti-inflammatory SCFAs. The impact of the intestinal microbiome on intestinal physiological functions is multifaceted. It participates in the digestion and absorption of nutrients, regulates intestinal immune function, maintains intestinal homeostasis, etc., and plays a vital role in maintaining intestinal health role.

Jackson et al. (2019) discussed how intestinal microbes influence the inflammatory response in the intestine and the development of intestinal cancer through communication with host cell mitochondria. In-depth study of the relationship between the intestinal microbiome and intestinal physiological functions is of great significance for understanding the nature of intestinal health and developing disease prevention and treatment strategies based on the intestinal microbiome.

2.2 Association between intestinal microbiome and intestinal diseases

The imbalance of the intestinal microbiome is closely related to the occurrence and development of various intestinal diseases. Sokol et al. (2017) found that the composition of the intestinal microbiome in patients with inflammatory bowel disease (including Crohn's disease and ulcerative colitis) changed significantly, especially the number of protective bacteria such as *Faecalibacterium prausnitzii* in the phylum Firmicutes was reduced. , while the number of certain potentially harmful bacteria such as Proteobacteria increases. This microbiome imbalance is closely related to the occurrence and development of intestinal inflammation.

Lee et al. (2022) have shown that imbalance of the intestinal microbiome may lead to the occurrence of metabolic diseases such as insulin resistance and obesity. Certain members of the intestinal microbiome may be involved in the occurrence and development of intestinal tumors by producing carcinogens and promoting the growth of tumor cells.

After reviewing multiple literatures, Talapko et al. (2022) reviewed the role of intestinal microbiome imbalance (dysbiosis) in the pathogenesis of inflammatory bowel disease, as well as potential therapeutic strategies to restore the balance of the intestinal microbiome.

2.3 The role of intestinal microbiome in maintaining intestinal homeostasis

Intestinal homeostasis refers to the relatively stable state of the intestinal environment, which is of great significance to maintaining intestinal health. The gut microbiome plays a key role in maintaining intestinal homeostasis. The intestinal microbiome provides necessary nutrition and support for intestinal cells by participating in the digestion and absorption of nutrients and synthesizing vitamins. The intestinal microbiome maintains the intestinal environment by regulating immune responses and inhibiting the reproduction of harmful bacteria Stable.

Shi et al. (2017) found that a healthy intestinal microbiome promotes intestinal health through interaction with the intestinal immune system, while microbiome imbalance (Dysbiosis) may lead to the occurrence of intestinal diseases. Furthermore, the impact of the gut microbiome on the integrity of the intestinal mucosal barrier and its long-term impact on intestinal health are discussed.

After reviewing many documents, Lee et al. (2022) explained how a high-fat diet disrupts intestinal oxygen control and nitrate exposure, leading to changes in the intestinal microbiome, and discussed intervening in the intestinal microbiome by regulating host intestinal physiology. Potential pathways for imbalance. The gut microbiome is critical for maintaining the integrity and function of the intestinal barrier. The intestinal barrier prevents harmful substances and pathogens from entering the intestines and protects intestinal health.

3 Research Situation

3.1 Intestinal microbiome and intestinal inflammatory diseases

In recent years, the relationship between the gut microbiome and intestinal inflammatory diseases has attracted widespread attention. Research shows that dysbiosis of the gut microbiome plays an important role in the pathogenesis of inflammatory bowel diseases (IBD) such as Crohn's disease and ulcerative colitis. The number of beneficial bacteria in the patient's intestines decreases, while harmful bacteria increase, leading to an imbalance in the intestinal environment. Certain gut bacteria can trigger abnormal immune responses, further exacerbating intestinal inflammation.

Curtis Huttenhower, a member of the HMP2 project and the leader of this study, Professor of Computational Biology and Bioinformatics at Harvard University, and his colleagues followed 132 participants for a year , conducted multi-dimensional molecular profiling analysis of the samples, and observed for the first time A complex series of chemical and molecular events (Lloyd-Price et al., 2019). They can disrupt the microbiota during the pathogenesis of IBD and trigger immune responses, and biochemical differences in IBD patients during dysbiosis, such as dramatic changes in acylcarnitine levels (Figure 2).

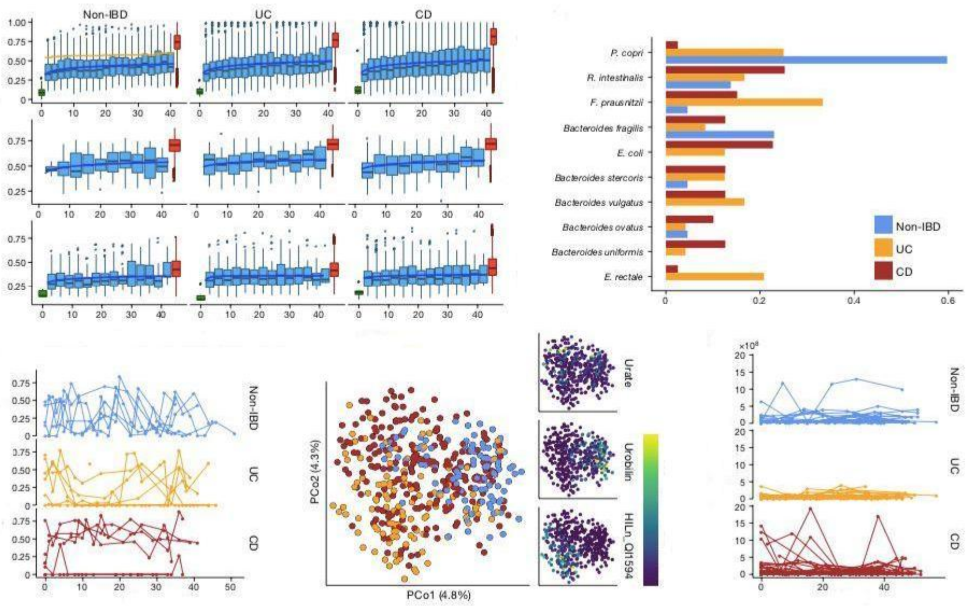

Figure 2 The microbiome changes are more frequent and extreme in IBD patients (Lloyd-Price et al., 2019)

3.2 Intestinal microbiome and intestinal metabolic diseases

There is also a close connection between the intestinal microbiome and intestinal metabolic diseases. Studies have shown that imbalance of the intestinal microbiome may lead to the occurrence of metabolic diseases such as obesity and diabetes (Gu et al., 2019). Certain intestinal bacteria can promote the absorption and storage of fat, leading to obesity. The gut microbiome can also influence the host's absorption and utilization of glucose, thereby affecting blood sugar levels.

Chassaing et al. (2015) found that intestinal metabolic diseases can be prevented and treated by regulating the composition and function of the intestinal microbiome. For example, increasing dietary fiber intake can promote the growth of beneficial bacteria and improve the intestinal environment, thereby preventing the occurrence of obesity and diabetes. Several drugs and treatments have also been shown to treat intestinal metabolic diseases by modulating the gut microbiome.

Boulangé et al. (2016) explored the importance of symbiotic interactions between the gut microbiota and the host in regulating human metabolism. In particular, we discuss how alterations in gut microbiome structure are associated with increased incidence of metabolic and immunological diseases in animals and humans.

3.3 Gut microbiome delays aging through butyrate

A research team led by Professor Sven Pettersson from the Lee Kong Chian School of Medicine at Nanyang Technological University transplanted gut microbes from old donor mice (24 months old) into young germ-free recipient mice (six weeks old) (Kundu et al., 2019). After eight weeks, the mice showed intestinal growth and hippocampal neurogenesis (the production of neurons) in the brain. Research shows that neurogenesis is due to the enrichment of gut microbes that produce a specific short-chain fatty acid, butyrate.

Shi et al. (2017) study emphasized the role of commensal microorganisms in maintaining intestinal homeostasis. An imbalanced microbiome leads to immune dysfunction by affecting the maturation of the mucosal immune system, thereby promoting disease. The intestinal mucosal immune system forms a protective barrier for intestinal integrity, and its composition is under the surveillance of the normal mucosal immune system. Inflammation caused by an abnormal immune response can affect the balance of the gut microbiome and lead to intestinal disease.

Yoo et al. (2020) found that intestinal flora imbalance or negative changes in the composition of intestinal microorganisms can also dysregulate the immune response, causing inflammation, oxidative stress, and insulin resistance. Over time, chronic dysbiosis and the translocation of bacteria and their metabolites across mucosal barriers may increase the prevalence of type 2 diabetes, cardiovascular disease, inflammatory bowel disease, autoimmune diseases, and various cancers.

3.4 Interaction between intestinal microbiome and host genes

The interaction between the intestinal microbiome and host genes is also one of the important directions of current research. Studies by Hills et al. (2019) have shown that the intestinal microbiome can affect the expression and regulation of host genes, thereby participating in the regulation of host physiological and pathological processes. Host genes also influence the composition and function of the gut microbiome. Some genes can affect the diversity and stability of the gut microbiome, thereby affecting gut health. The intestinal microbiome can also affect the expression and regulation of host genes through epigenetic mechanisms, such as DNA methylation.

On January 3, 2024, Professor Fu Jingyuan’s team from the University Medical Center of Groningen in the Netherlands published a research paper in the form of a long article in Nature magazine. Based on a large-scale population cohort, this work established the genome-genome association between humans and intestinal microorganisms for the first time, and discovered specific nutritional components determined by the host genetic background, which can screen intestinal microbial strains carrying specific genome fragments. (Zhernakova et al., 2024). Through in-depth study of these relationships, it was found that the association between intestinal microorganisms and host health is also regulated by the host's genetic background, which also provides an important reference for individualized targeted flora intervention. Through large-scale association analysis, this study revealed that human The regulatory relationship between the first and second genomes provides an important theoretical supplement to the human body-symbiotic microbial interaction mechanism and emphasizes the reliability of the microbiome research paradigm dominated by microbial genetic diversity.

4 Conclusion and Outlook

4.1 Future directions of intestinal microbiome research

With the deepening of research on the human microbiome, especially the intestinal microbiome, future research directions will become more diversified and refined. More attention will be paid to the differences in the intestinal microbiome among different groups of people and under different disease states, in order to find microbial markers related to specific diseases. Research will be devoted to analyzing the interaction mechanism between the intestinal microbiome and the host, including how microorganisms affect host gene expression, metabolic processes, and the immune system.

For example, a study by Franzosa et al. (2019) revealed microbial markers associated with disease activity by analyzing the gut microbiome of patients with inflammatory bowel disease, which helps to better understand the microbial mechanisms and potential treatments for IBD. target. These technologies will also help to better understand and harness the potential of the gut microbiome for health maintenance, disease prevention and treatment.

Cani (2018) discusses the promises, potential threats, and prospects that the study of the human gut microbiome holds for the development of new treatments, particularly in the context of metabolic diseases. With the continuous advancement of technology, the application of high-throughput technologies such as single-cell sequencing and metabolomics will enable this study to gain a deeper understanding of the complexity and diversity of the intestinal microbiome.

4.2 Challenges and problems faced

Although gut microbiome research has made significant progress, many challenges and issues remain. The complexity of the gut microbiome means that understanding of its function remains limited. Although many microorganisms related to intestinal health have been identified, their roles and interrelationships in the intestinal ecosystem still require further study. Yoo et al. (2020) studied the dynamics between the intestinal microbiome and the host immune system. interactions, which are critical for maintaining intestinal homeostasis and suppressing inflammation. The gut microbiome mediates communication between intestinal epithelial cells and immune cells by metabolizing proteins and complex carbohydrates, synthesizing vitamins, and producing numerous metabolites. The mucosal barrier produced by intestinal epithelial cells helps separate microorganisms from host immune cells and reduces intestinal permeability. An imbalance in the gut microbiome disrupts this interaction, leading to an increase in pathogens and associated metabolic changes that disrupt the epithelial barrier and increase susceptibility to infection.

The interaction mechanism between the intestinal microbiome and the host has not been fully elucidated , and a deeper understanding of how microorganisms communicate with host cells, immune system, etc. is needed, and how this communication affects the host's physiological and pathological processes. How to apply the research results of intestinal microbiome into clinical practice is also an urgent problem to be solved. Anand and Mande (2018) explored the connection between the gut microbiome and lung health, highlighting the role of diet in regulating the gut-lung axis and the importance of studying the gut microbiome for understanding and treating respiratory diseases.

4.3 Summary of the impact of human microbiome on intestinal health

The human microbiome, especially the intestinal microbiome, has a profound and widespread impact on intestinal health. They participate in physiological processes such as the digestion and absorption of nutrients, the synthesis of vitamins, and the generation of metabolites, and play a key role in maintaining intestinal homeostasis (Hills et al., 2019). The gut microbiome also interacts with the intestinal immune system to defend against invasion by foreign pathogens.

When the intestinal microbiome is imbalanced, it may lead to the occurrence and development of various intestinal diseases, such as inflammatory bowel disease, metabolic diseases, etc. Therefore, in-depth study of the relationship between the intestinal microbiome and intestinal health is of great scientific significance and practical value for understanding the pathogenesis of intestinal diseases and developing new disease diagnosis and treatment strategies. Feng et al. (2018) discussed the intestinal The interaction between the gut microbiome and physical organs and systems, including the brain, lungs, liver, bones, cardiovascular system, etc., highlights the microbiota's role as a primary signal connecting the gut through metabolites such as short-chain fatty acids such as butyrate. Microbiome and physiological function.

Sommer et al. (2017) discussed how the resilience of the gut microbiome affects health and disease, including their critical role in maintaining intestinal homeostasis and preventing inflammatory bowel disease and metabolic diseases. Looking to the future, as research continues to deepen and technology advances, it is believed that intestinal microbiome research will bring more new understandings and discoveries about intestinal health and diseases. These research results will also provide new ideas and methods for human health maintenance and disease prevention and treatment.

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