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The gut microbiome and its influence on chronic diseases: A public health approach to prevention and intervention

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Abstract

The gut microbiome, a diverse community of microorganisms residing in the human gastrointestinal tract, plays a critical role in maintaining overall health. Emerging evidence suggests that alterations in the gut microbiota are associated with various chronic diseases, including obesity, type 2 diabetes, cardiovascular diseases, inflammatory bowel disease, and neurological disorders. Understanding the complex interactions between the gut microbiome and host physiology offers new opportunities for disease prevention and intervention. This review explores the relationship between the gut microbiome and chronic diseases, emphasizing public health strategies for prevention and intervention, including dietary modifications, probiotics, prebiotics, and microbiome-targeted therapies.

Keywords: Gut microbiome; Chronic diseases; Public health; Gut microbiota; Probiotics; Prebiotics

1. Introduction

Chronic diseases, such as diabetes, cardiovascular diseases, and inflammatory disorders, are among the leading causes of morbidity and mortality worldwide. The gut microbiome has emerged as a critical player in modulating immune responses, metabolic processes, and overall homeostasis [1]. This review provides a comprehensive analysis of the gut microbiome's influence on chronic diseases and explores public health approaches aimed at leveraging microbiome research for prevention and intervention [2].

2. The Gut Microbiome: Composition and Function

The gut microbiome consists of trillions of microorganisms, including bacteria, fungi, viruses, and archaea. The predominant bacterial phyla include Firmicutes, Bacteroidetes, Actinobacteria, and Proteobacteria [2]. The microbiome plays essential roles in:

- **Digestion and Metabolism**: Microbial enzymes facilitate the breakdown of complex carbohydrates and fiber, producing short-chain fatty acids (SCFAs) that influence metabolic health [3]
- **Immune System Modulation**: The microbiota helps regulate immune responses and protect against pathogens.

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- **Neurotransmitter Production**: Gut bacteria synthesize neurotransmitters, such as serotonin and gamma-aminobutyric acid (GABA), influencing brain function.
- **Inflammation Control**: A balanced microbiome contributes to gut barrier integrity and prevents systemic inflammation [4].

2.1. Effect of Gut Microbiome on Chronic Disease

There are several ways by which gut microbiome affects chronic diseases. Microbial composition is significantly altered in obesity, with an increased Firmicutes-to-Bacteroidetes ratio associated with enhanced energy harvest from food. Dysbiosis contributes to metabolic inflammation, insulin resistance, and adiposity [5]. Studies have shown that interventions such as fiber-rich diets, probiotics, and fecal microbiota transplantation (FMT) can restore microbiome balance and improve metabolic health [6]. Moreover, gut microbiota composition influences glucose metabolism, insulin sensitivity, and inflammation [7]. In diabetic individuals, a reduction in butyrate-producing bacteria and an increase in pro-inflammatory microbes are observed. Probiotics and prebiotics targeting gut dysbiosis have shown promise in improving glycemic control and reducing inflammation [8].

According to the [9], certain bacterial species produce trimethylamine N-oxide (TMAO), which is linked to atherosclerosis. Dietary modifications, including increased fiber intake and reduced consumption of red meat, can modulate microbiome composition and lower CVD risk. IBD, including Crohn's disease and ulcerative colitis, is associated with reduced microbial diversity and an overgrowth of pathogenic bacteria [10]. Gut dysbiosis contributes to intestinal inflammation and epithelial damage. Therapeutic strategies, such as probiotics, dietary modifications, and microbiota-based therapies, have shown potential in managing IBD symptoms.

Furthermore, the gut-brain axis connects microbiome alterations to neurological diseases such as depression, anxiety, and Alzheimer's disease. Microbial metabolites, including SCFAs and neurotransmitters, influence neuroinflammation and cognitive function. Microbiota-targeted interventions, including probiotics and psychobiotics, offer new avenues for managing neurological disorders [11].

2.2. Public Health Approaches to Prevention and Intervention

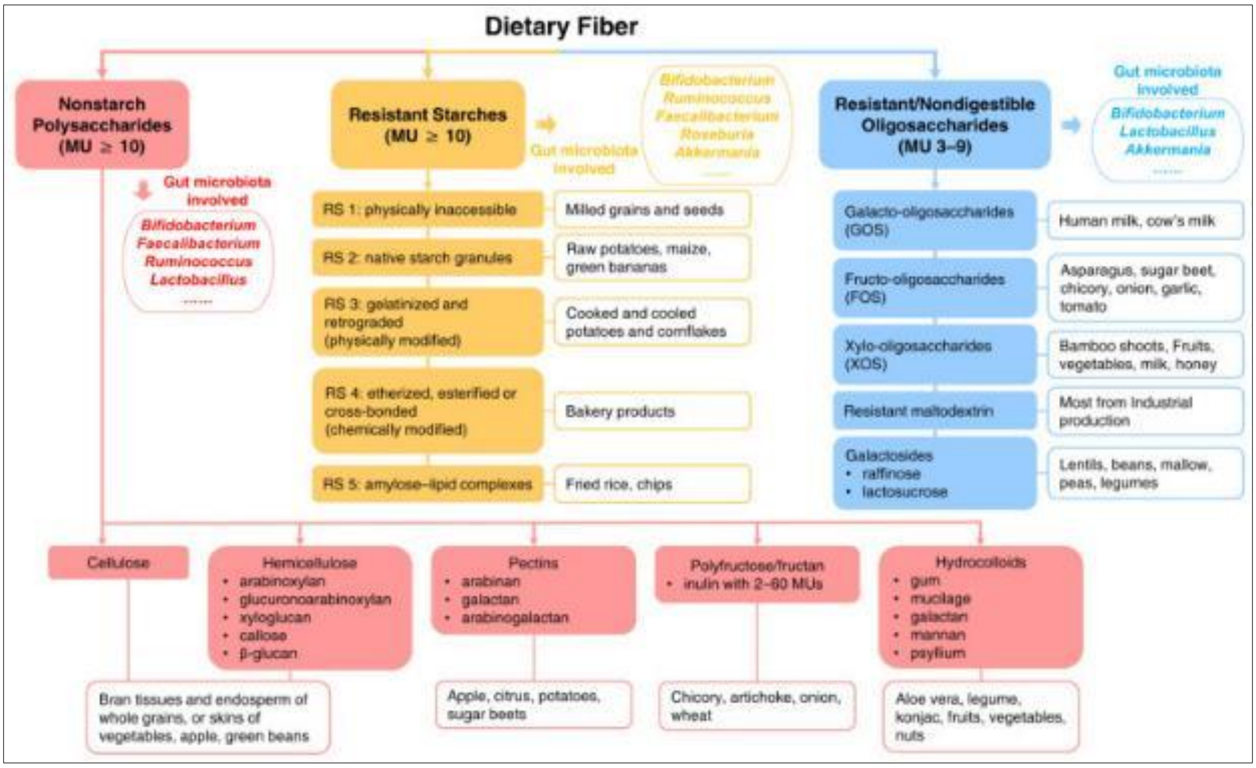

Figure 1 Type of dietary fiber (Monomeric Unit) [14].

The gut microbiome plays a crucial role in digestion, immune function, and overall health [12]. Emerging research highlights the profound impact of dietary habits on microbial diversity and gut health. A diet rich in fiber, polyphenols, and fermented foods fosters a balanced microbiome, reducing the risk of metabolic disorders, inflammatory conditions, and chronic diseases [13]. Meanwhile, public health initiatives and individual dietary choices should prioritize certain following key modifications.

First, increased fiber intake. One of the most effective dietary strategies for gut health is increasing fiber intake [14]. Fiber serves as a primary energy source for beneficial gut bacteria, stimulating their growth and enhancing metabolic functions. Whole grains, legumes, fruits, and vegetables are particularly rich sources of fiber, fostering microbial diversity and facilitating the production of short-chain fatty acids (SCFAs) such as butyrate, propionate, and acetate [15]. These SCFAs play a crucial role in maintaining gut barrier integrity, regulating immune function, and reducing inflammation. Epidemiological studies indicate that populations with high fiber consumption have lower rates of obesity, type 2 diabetes, and cardiovascular diseases, underscoring the importance of fiber in maintaining gut and metabolic health [16].

Ultra-processed foods, including refined carbohydrates, processed meats, and artificial additives, disrupt microbial balance [17]. These foods encourage the proliferation of pathogenic bacteria while reducing beneficial species, leading to increased gut permeability (leaky gut syndrome) and systemic inflammation. Studies have linked high consumption of ultra-processed foods to an increased prevalence of chronic conditions such as obesity, type 2 diabetes, and autoimmune diseases [18]. Shifting toward whole, minimally processed foods can restore microbial equilibrium and improve gut resilience.

[19] wrote that fermented foods such as yogurt, kimchi, kefir, miso, and sauerkraut are rich in probiotics—live beneficial bacteria that enhance gut microbiota composition. These foods help restore microbial balance, strengthen the gut barrier, and modulate immune responses. Regular consumption of fermented foods has been associated with reduced inflammation, improved digestion, and a lower risk of gastrointestinal disorders like irritable bowel syndrome (IBS) and inflammatory bowel disease (IBD) [20].

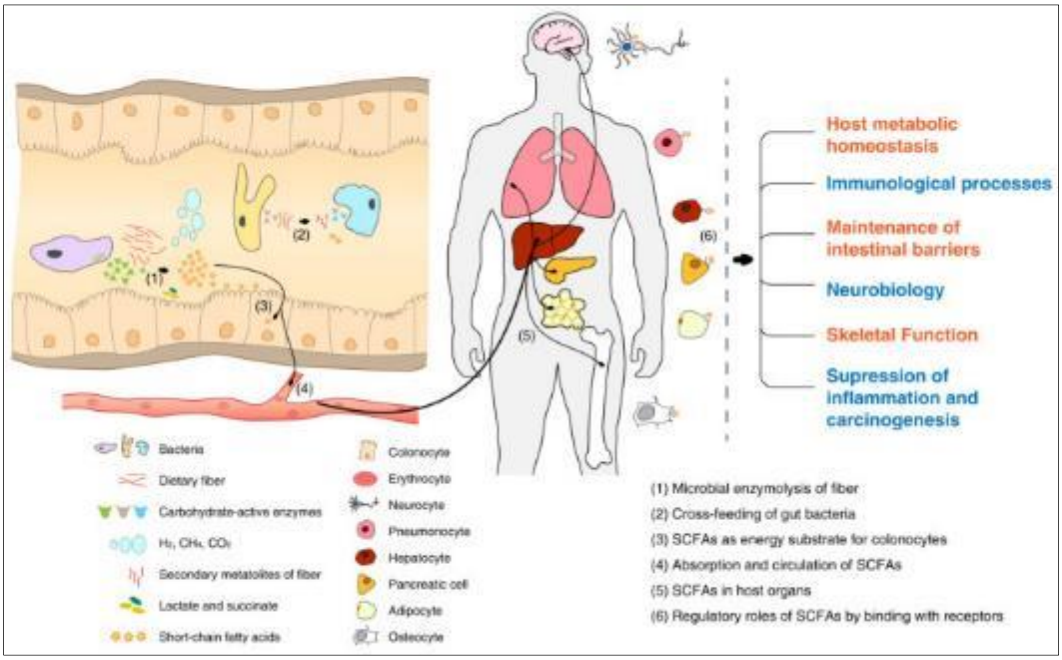

Figure 2 Dietary fiber fermentation by gut microbiota [14]

Also, according to [21], polyphenols are bioactive compounds found in foods such as dark chocolate, berries, green tea, red wine, nuts, and olive oil. These compounds act as prebiotics, selectively nourishing beneficial gut bacteria like *Lactobacillus* and *Bifidobacterium*. Polyphenols possess strong antioxidant and anti-inflammatory properties, reducing oxidative stress and supporting gut-brain communication [22]. Studies suggest that polyphenol-rich diets contribute to improved cognitive function, cardiovascular health, and reduced risk of neurodegenerative diseases.

The Mediterranean diet, characterized by high consumption of plant-based foods, healthy fats (such as olive oil and nuts), and lean proteins, has been extensively studied for its positive effects on gut microbiome diversity [23]. This diet promotes the growth of beneficial microbes while reducing inflammatory markers associated with metabolic disorders.

Evidence suggests that adherence to the Mediterranean diet correlates with a lower incidence of obesity, type 2 diabetes, and cardiovascular diseases [24].

Moreover, excessive sugar intake and artificial sweeteners such as aspartame and sucralose negatively impact gut microbiota composition [25]. These substances contribute to dysbiosis (microbial imbalance), increase the presence of harmful bacteria, and disrupt glucose metabolism. High sugar consumption has been linked to insulin resistance, increased fat deposition, and chronic inflammation [26]. Reducing sugar intake and opting for natural sweeteners like honey or stevia can help maintain a balanced gut microbiome and metabolic health.

[27] observed that a well-balanced diet that prioritizes fiber, fermented foods, polyphenol-rich options, and whole foods while reducing ultra-processed products, sugar, and artificial additives is essential for maintaining a thriving gut microbiome. Therefore, public health initiatives should emphasize the importance of these dietary strategies in preventing chronic diseases and promoting long-term well-being.

2.3. Probiotics and Prebiotics

2.3.1. Probiotics and Prebiotics: Fundamental Components of Gut Health and Their Broader Implications

The human gut microbiome plays a critical role in maintaining overall health, with an intricate balance of microorganisms influencing digestion, immune function, and even neurological processes [28]. Among the key modulators of this microbial ecosystem are probiotics, prebiotics, synbiotics, and postbiotics, each contributing distinct but interrelated benefits [29]. Understanding these elements is crucial for leveraging their therapeutic potential in disease prevention and management.

2.3.2. Probiotics: Beneficial Microorganisms Supporting Gut Health

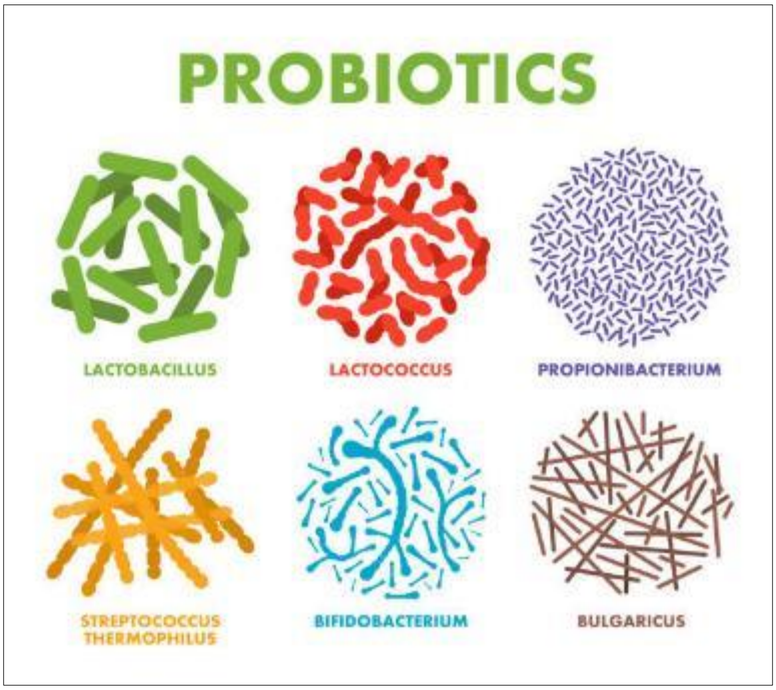

Figure 3 Probiotics

Probiotics are live microorganisms that, when administered in adequate amounts, confer significant health benefits [30]. These beneficial bacteria primarily belong to the genera *Lactobacillus* and *Bifidobacterium*, which have been extensively studied for their ability to improve gut microbiota composition. *Lactobacillus* species are known for their ability to metabolize lactose, regulate intestinal pH, and produce antimicrobial substances that inhibit pathogenic bacteria [31]. Similarly, *Bifidobacterium* species contribute to gut homeostasis by fermenting complex carbohydrates into short-chain fatty acids (SCFAs), which play a crucial role in reducing inflammation and enhancing immune responses [32].

The health benefits of probiotics extend beyond gut health. Studies have demonstrated their effectiveness in preventing and managing conditions such as irritable bowel syndrome (IBS), inflammatory bowel disease (IBD), and antibiotic-associated diarrhea [33]. Furthermore, emerging research highlights their influence on the gut-brain axis, suggesting that probiotics can modulate mood, cognition, and stress responses. This is particularly relevant in neuropsychiatric disorders such as anxiety and depression, where gut microbiota dysbiosis has been implicated as a contributing factor [34].

2.3.3. Prebiotics: Nourishing the Gut Microbiota

Prebiotics are non-digestible food components that selectively stimulate the growth and activity of beneficial gut bacteria [35]. These compounds primarily consist of dietary fibers such as inulin, fructooligosaccharides (FOS), and galactooligosaccharides (GOS), which resist digestion in the upper gastrointestinal tract and reach the colon, where they serve as substrates for fermentation by commensal bacteria. The fermentation process leads to the production of SCFAs, including butyrate, propionate, and acetate, which play a vital role in maintaining gut barrier integrity, modulating immune function, and regulating metabolic processes [36].

In addition to supporting gut microbiota, prebiotics have been shown to enhance calcium and magnesium absorption, thus contributing to bone health. Their ability to regulate bowel movements and alleviate constipation is particularly beneficial for individuals suffering from gastrointestinal disorders [37]. Moreover, prebiotics exhibit immunomodulatory properties by enhancing the activity of gut-associated lymphoid tissue (GALT), thereby strengthening the body's defense against infections and inflammatory conditions.

2.3.4. Synbiotics: The Synergistic Combination of Probiotics and Prebiotics

Synbiotics represent a strategic approach that combines probiotics with prebiotics to maximize their beneficial effects [38]. The rationale behind this combination lies in the provision of an optimal environment for probiotic bacteria to thrive, ensuring their survival and colonization within the gastrointestinal tract. This symbiotic relationship has been shown to enhance gut microbiota resilience, particularly in individuals recovering from antibiotic treatments or suffering from dysbiosis-related conditions [39].

Clinical applications of synbiotics extend to metabolic disorders, where they have demonstrated potential in improving insulin sensitivity and lipid metabolism. Research also suggests that synbiotics may contribute to weight management by influencing gut-derived satiety hormones and reducing systemic inflammation associated with obesity [40]. Given their multifaceted health benefits, synbiotics are increasingly being incorporated into functional foods, dietary supplements, and clinical nutrition programs.

2.3.5. Postbiotics: Metabolic Byproducts with Therapeutic Potential

Postbiotics are bioactive compounds produced during the fermentation process of probiotics, exerting a wide range of health-promoting effects. These metabolites include SCFAs, antimicrobial peptides, and cell wall fragments that influence gut health, immune regulation, and metabolic pathways [41]. Butyrate, a key postbiotic, has been extensively studied for its ability to strengthen the gut barrier, reduce intestinal permeability, and mitigate inflammatory responses associated with gastrointestinal disorders [42].

Beyond gut health, postbiotics play a crucial role in modulating systemic immune responses. They have been shown to enhance the production of anti-inflammatory cytokines while suppressing pro-inflammatory mediators, thereby reducing the risk of chronic inflammatory diseases [43]. The antimicrobial properties of certain postbiotic compounds further contribute to their therapeutic potential by inhibiting pathogenic bacterial colonization and maintaining gut microbiota balance. As a result, postbiotics are being explored as potential alternatives to traditional probiotic interventions, particularly in populations with compromised gut integrity or immune function [44].

3. Public Health Implications: Integrating Gut Health into Preventive Strategies

Given the growing body of evidence supporting the role of gut microbiota in overall health, public health initiatives should prioritize strategies that promote the consumption of probiotics and prebiotics [45]. Governments and health organizations can play a pivotal role by launching awareness campaigns that educate the population on the benefits of gut health optimization. Integrating probiotics and prebiotics into national dietary guidelines and food policies can further encourage their widespread adoption [46].

Regulatory measures, such as standardized labeling of probiotic-containing foods and supplements, can enhance consumer awareness and facilitate informed decision-making [20]. Additionally, incorporating probiotics and prebiotics into school meal programs and workplace wellness initiatives can contribute to long-term health improvements at a population level. Such initiatives not only support digestive health but also have broader implications for immune function, mental well-being, and chronic disease prevention [47].

As shown in Figure 4, the intricate relationship between probiotics, prebiotics, synbiotics, and postbiotics underscores the importance of gut microbiota in maintaining overall health. By fostering a balanced gut environment, these components play a crucial role in digestion, immune regulation, and metabolic homeostasis [48]. Advances in microbiome research continue to unveil new therapeutic applications, highlighting the need for integrating gut health optimization into clinical practice and public health policies. As scientific understanding evolves, leveraging these natural interventions holds immense potential for enhancing human health and disease prevention in a sustainable manner.

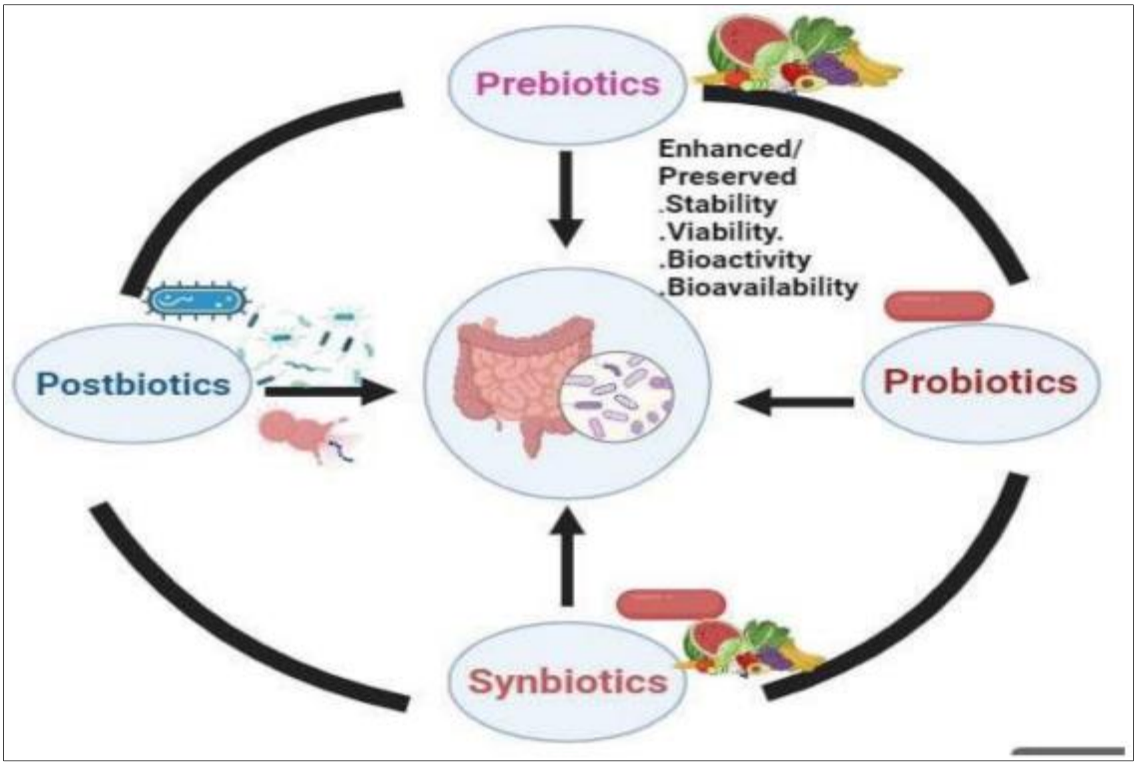

Figure 4 Interaction of postbiotics, synbiotics, probiotics, and prebiotics [48]

3.1. Microbiome-Based Therapies and Their Implications for Human Health

The human microbiome, composed of trillions of microorganisms residing primarily in the gut, plays a fundamental role in health and disease [49]. With advancements in microbiome research, novel therapeutic approaches are emerging that aim to restore microbial balance and enhance overall well-being. These microbiome-based therapies offer promising avenues for addressing gastrointestinal disorders, metabolic conditions, and even immune-related diseases [50].

3.2. Fecal Microbiota Transplantation (FMT): A Revolution in Microbiome Restoration

Fecal microbiota transplantation (FMT) has gained significant attention as an effective treatment for recurrent *Clostridium difficile* infections (CDI), a condition characterized by severe diarrhea and colitis [51]. The procedure involves transferring fecal microbiota from a healthy donor into a recipient's gut, thereby restoring microbial diversity and suppressing pathogenic bacteria. Clinical trials have demonstrated an efficacy rate of over 90% in CDI patients, surpassing standard antibiotic treatments [52].

Beyond CDI, FMT is being investigated for its potential in treating other conditions, including ulcerative colitis, Crohn's disease, and metabolic disorders such as obesity and type 2 diabetes. The gut microbiome's influence on immune regulation and systemic inflammation suggests that FMT may also play a role in modulating autoimmune diseases and neuropsychiatric disorders [53]. However, challenges remain in standardizing donor screening, optimizing delivery methods, and ensuring long-term safety. Future research aims to refine FMT protocols and explore the development of synthetic microbiota-based formulations that eliminate the need for donor-derived material [54].

3.3. Microbiome Modulators: Engineered Solutions for Gut Health

The emergence of microbiome modulators represents a targeted approach to restoring gut balance. These therapies include small-molecule drugs, prebiotic formulations, and genetically engineered bacteria designed to modulate microbial communities and metabolic pathways [55]. For example, next-generation probiotics (*Akkermansia muciniphila* and *Faecalibacterium prausnitzii*) are being explored for their anti-inflammatory properties and potential applications in treating inflammatory bowel diseases (IBD) and metabolic syndrome.

Engineered bacteria have also opened new possibilities in microbiome therapy. By modifying bacterial strains to produce therapeutic compounds, researchers are developing precision treatments for conditions such as phenylketonuria, where engineered gut microbes help break down toxic metabolites [56]. These advancements pave the way for microbiome-based precision medicine, where microbial interventions are tailored to an individual's unique gut composition and disease profile.

3.4. Personalized Nutrition: The Microbiome's Role in Dietary Interventions

Personalized nutrition, informed by microbiome profiling, is revolutionizing dietary recommendations and metabolic health management [57]. Research indicates that individuals respond differently to the same foods due to variations in their gut microbiota. By analyzing an individual's microbiome composition, personalized nutrition approaches can tailor diets to optimize digestion, nutrient absorption, and metabolic function [58].

This concept is particularly relevant in managing obesity, diabetes, and cardiovascular diseases, where gut bacteria influence glucose metabolism, lipid absorption, and inflammatory responses. Advanced sequencing technologies and artificial intelligence-driven analyses are enabling the development of microbiome-based dietary interventions that predict optimal food choices for maintaining gut balance and preventing chronic diseases [59]. As personalized nutrition gains traction, integration into clinical practice will require robust validation and widespread accessibility to microbiome testing.

3.5. Probiotic Pharmaceuticals: A New Frontier in Chronic Disease Management

The development of pharmaceutical-grade probiotics marks a significant advancement in microbiome-based medicine. Unlike conventional probiotic supplements, which often contain variable strains and dosages, probiotic pharmaceuticals undergo rigorous clinical testing to ensure efficacy and safety [60]. These therapeutic probiotics are being formulated to target specific diseases, including IBD, irritable bowel syndrome (IBS), and atopic dermatitis.

For instance, probiotic strains such as *Lactobacillus reuteri* and *Bifidobacterium longum* have demonstrated immunomodulatory effects that could benefit patients with autoimmune conditions and allergies. Additionally, research is exploring the role of probiotics in mental health, with emerging evidence suggesting that certain strains can influence neurotransmitter production and reduce symptoms of anxiety and depression through the gut-brain axis [61]. As the field advances, regulatory bodies will need to establish clear guidelines to differentiate probiotic pharmaceuticals from over-the-counter supplements, ensuring consistent quality and therapeutic reliability.

3.6. Microbiome-Based Vaccines: Enhancing Immunity Through Gut Bacteria

The interplay between the gut microbiome and the immune system has led to growing interest in microbiome-based vaccines. Research indicates that gut bacteria influence vaccine efficacy by modulating immune responses and enhancing antigen presentation [62]. Scientists are investigating whether specific microbial strains can serve as adjuvants to improve immune memory and vaccine potency. For example, studies suggest that individuals with a diverse gut microbiota exhibit stronger immune responses to vaccines such as influenza and rotavirus. Microbiome-based strategies are also being explored in cancer immunotherapy, where gut bacteria have been shown to enhance the effectiveness of immune checkpoint inhibitors. Understanding these interactions could lead to the development of microbiome-derived vaccine adjuvants and novel immunization strategies that harness the power of gut microbes to improve disease resistance [63].

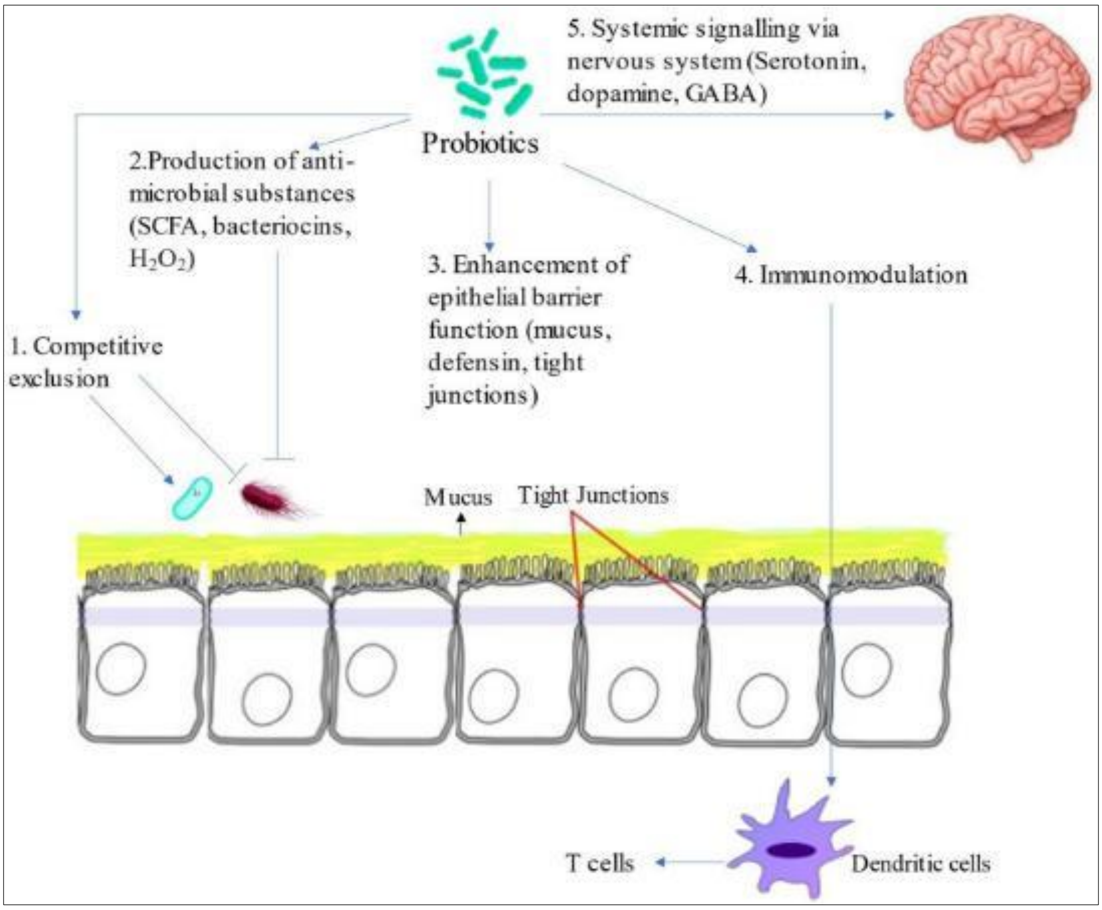

Figure 5 Probiotics pharmaceuticals for chronic disease management [60]

4. Public Health Campaigns and Policies

The human microbiome, composed of trillions of microorganisms residing primarily in the gut, plays a fundamental role in health and disease. With advancements in microbiome research, novel therapeutic approaches are emerging that aim to restore microbial balance and enhance overall well-being [2]. These microbiome-based therapies offer promising avenues for addressing gastrointestinal disorders, metabolic conditions, and even immune-related diseases [64].

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Public awareness campaigns play a vital role in educating individuals about the importance of maintaining a healthy gut microbiome [67]. Schools, healthcare institutions, and government agencies can implement educational initiatives that emphasize the benefits of a diverse diet rich in fiber, probiotics, and prebiotics. Community workshops and digital health platforms can further disseminate information on microbiome-friendly lifestyle choices, such as reducing antibiotic overuse and avoiding processed foods that disrupt microbial balance [2].

4.1. Regulatory Frameworks: Ensuring Quality Control in Microbiome-Based Products

With the rise of probiotic and microbiome-related products, stringent regulatory frameworks are necessary to ensure consumer safety and product efficacy. Currently, many commercially available probiotics lack standardized formulations and undergo minimal clinical validation [68]. Establishing clear guidelines for probiotic labeling, potency verification, and strain-specific benefits will help consumers make informed choices. Regulatory agencies must also oversee the safety of emerging microbiome therapies, including FMT and engineered probiotics, to prevent potential risks associated with microbial imbalances and opportunistic infections [69].

According to, implementing microbiome-friendly dietary initiatives in schools, workplaces, and public institutions can significantly impact long-term health outcomes [70]. Schools can incorporate probiotic-rich foods such as yogurt and fermented vegetables into meal programs, while workplaces can promote gut health through wellness initiatives and microbiome education. Healthcare providers can also integrate microbiome assessments into routine check-ups, offering personalized dietary recommendations to optimize gut health [51].

Moreover, accurate food labeling is crucial for consumers seeking to improve their gut health. Mandating clear disclosures on probiotic and prebiotic content in food products can empower individuals to make informed dietary choices [71]. Also, standardized definitions of microbiome-friendly foods can help distinguish scientifically validated products from those making unsubstantiated health claims. Countries that have implemented transparent food labeling policies have seen improved public trust in functional foods and dietary interventions [72].

4.2. Research Funding: Advancing Microbiome Science for Public Health

Sustained investment in microbiome research is essential for uncovering new therapeutic applications and public health strategies. Government agencies, research institutions, and private sectors should collaborate to fund large-scale studies exploring the microbiome’s role in chronic disease prevention, mental health, and personalized medicine [73]. Expanding microbiome-focused clinical trials will provide evidence-based insights that can inform policy decisions and healthcare recommendations. Microbiome-based therapies represent a transformative frontier in medicine, offering new solutions for treating gastrointestinal disorders, metabolic diseases, and immune-related conditions [74]. From FMT and engineered probiotics to microbiome-based vaccines, these innovations underscore the growing recognition of gut health as a cornerstone of overall well-being. As scientific research advances, integrating microbiome awareness into public health policies, regulatory frameworks, and community interventions will be essential in harnessing the full potential of microbiome science for disease prevention and health promotion [75].

5. Conclusion

The gut microbiome is an integral component of human health, influencing digestion, immunity, metabolic regulation, and even neurological function. As research continues to uncover the intricate relationships between microbial diversity and disease pathogenesis, it is becoming increasingly clear that microbiome-targeted interventions hold immense potential for chronic disease prevention and management. A comprehensive public health strategy that emphasizes dietary diversity, probiotic and prebiotic consumption, microbiome-based therapies, and large-scale educational initiatives can play a crucial role in reducing the burden of chronic illnesses such as obesity, diabetes, inflammatory bowel disease, and neurodegenerative conditions [7].

Advancements in microbiome science are paving the way for precision medicine, where personalized interventions tailored to an individual’s microbiota composition can optimize health outcomes. Personalized nutrition, probiotic pharmaceuticals, and engineered microbiome modulators are rapidly evolving fields that offer new treatment paradigms for managing complex diseases. Moreover, microbiome-based vaccines and immunotherapies highlight the profound impact of gut bacteria on immune function, opening new avenues for disease prevention and therapeutic innovation [49].

From a policy perspective, governments and regulatory agencies must take proactive measures to ensure quality control in microbiome-based products, establish clear labeling requirements, and fund large-scale research initiatives to bridge existing knowledge gaps [51]. Community-based interventions, such as integrating microbiome-friendly diets into school and workplace programs, can further promote public awareness and long-term health benefits [76].

Future research should prioritize not only expanding our understanding of microbiome-host interactions but also translating these findings into actionable healthcare solutions. Large-scale clinical trials, multi-omics approaches, and artificial intelligence-driven microbiome analyses will be critical in developing targeted therapies and refining public health recommendations [72]. By integrating microbiome science into mainstream healthcare practices and policy frameworks, we can harness its full potential to enhance human health, reduce healthcare costs, and mitigate the global burden of chronic diseases.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Authors Contribution

- **Mariam Oladayo Allison**: Conducted the core literature review on gut microbiome composition and function.
- **Millicent Yaa Gyasiwaa:** Coordinated the manuscript and led the public health and dietary intervention sections.
- **Damilola Egbewole**: Analyzed the microbiome's role in chronic diseases, focusing on diabetes and heart conditions.
- **Gbenga John Ilori:** Contributed to therapeutic innovations and helped structure technical content.
- **Baqi Atimah:** Worked on microbiome-based pharmaceuticals and vaccine-related content.
- **Ronke Victoria Olatunde:** Provided clinical input on the gut-brain axis and neurological health.

References

[1] G. Pepera, M. S. Tribali, L. Batalik and I. P. J. Petrov, "Epidemiology, risk factors and prognosis of cardiovascular disease in the Coronavirus Disease 2019 (COVID-19) pandemic era: a systematic review.," Reviews in Cardiovascular Medicine, vol. 23, no. 1, p. 28, 2022.

[2] N. Aggarwal, S. Kitano, G. R. Puah, S. Kittlemann, I. Y. Hwang and M. W. Chang, "Microbiome and human health: current understanding, engineering, and enabling technologies," Chemical Reviews, vol. 23, no. 1, pp. 31-72, 2022.

[3] P. Portincasa, L. Bonfrate, M. Vacca, M. De-Angelis, I. Farella, E. Lanza, M. Khalil, D. Q. Wang, M. Sperandio and A. Di-Ciaula, "Gut microbiota and short chain fatty acids: implications in glucose homeostasis," International Journal of Molecular Sciences, vol. 23, no. 3, p. 1105, 2022.

[4] F. Di-Vincenzo, A. Del-Gaudio, V. Petito, L. R. Lopetuso and F. Scaldaferri, "Gut microbiota, intestinal permeability, and systemic inflammation: a narrative review.," Internal and Emergency Medicine, vol. 19, no. 2, pp. 275-293, March 2024.

[5] G. G. Kang, N. L. Trevaskis, A. J. Murphy and M. A. Febbraio, "Diet-induced gut dysbiosis and inflammation: Key drivers of obesity-driven NASH," Iscience, vol. 20, no. 26, 20 Jan 2023.

[6] Y. Zhong, J. Cao, Y. Ma, Y. Zhang, J. Liu and H. Wang, "Fecal microbiota transplantation donor and dietary fiber intervention collectively contribute to gut health in a mouse model," Frontiers in Immunology, 3 Feb 2022.

[7] W. Bielka, A. Przezak and A. Pawlik, "The role of the gut microbiota in the pathogenesis of diabetes," International Journal of Molecular Sciences, vol. 23, no. 1, p. 480, 2022.

[8] P. Paul, R. Kaul, B. Abdellatif, M. Arabi, R. Upadhyay, R. Saliba, M. Sebah and A. Chaari, "The promising role of microbiome therapy on biomarkers of inflammation and oxidative stress in type 2 diabetes: A systematic and narrative review," Frontiers in Nutrition, vol. 9, 25 May 2022.

[9] L. Anto and C. N. Blesso, "Role of dysbiosis and microbial metabolites on inflammation and disordered lipid metabolism," The Journal of Nutritional Biochemistry, Vols. 1-5, no. 1, p. 108991, 2022.

[10] S. Kumar and A. Kumar, "Microbial Pathogenesis in Inflammatory Bowel Diseases," Microbial Pathogenesis, vol. 163, p. 105383, 1 Feb 2022.

[11] J. Missiego-Beltran and A. I. Beltran-Velasco, "The Role of Microbial Metabolites in the Progression of Neurodegenerative Diseases—Therapeutic Approaches: A Comprehensive Review," International Journal of Molecular Sciences, vol. 25, no. 18, p. 10041, 2024.

[12] P. Zhang, "Influence of Foods and Nutrition on the Gut Microbiome and Implications for Intestinal Health," International Journal of Molecular Sciences, vol. 23, no. 17, p. 9588, 2022.

[13] S. S. Gaur, "Fermented Foods in Traditional Therapies for Addressing Metabolic Disorders in Traditional Foods," The Reinvented Superfoods, pp. 427-454, 2024.

[14] J. Fu, Y. Zheng, Y. Gao and W. Xu, "Dietary Fiber Intake and Microbiota in Human Health," Microorganisms, vol. 10, no. 12, p. 2507, 18 Dec 2022.

[15] S. Kumar, R. Mukherjee, P. Gaur, E. Leal, X. Lyu, S. Ahmad, P. Puri, C. M. Chang, V. S. Raj and R. P. Pandey, "Unveiling Roles of Beneficial Gut Bacteria and Optimal Diets for Health," Frontiers in Microbiology, 18 Feb 2025.

[16] I. S. Waddell and C. Orfila, "Dietary Fiber in the Prevention of Obesity and Obesity-Related Chronic Diseases: From Epidemiological Evidence to Potential Molecular Mechanisms," Critical Reviews in Food Science and Nutrition, vol. 63, no. 27, pp. 8752-8767, 25 Oct 2023.

[17] D. Rondinella, P. C. Raoul, E. Valeriani, I. Venturini, M. Cintoni, A. Severino, F. S. Galli, V. Mora, M. C. Mele, G. Cammarota and A. Gasbarrini, "The Detrimental Impact of Ultra-Processed Foods on the Human Gut Microbiome and Gut Barrier," Nutrients, vol. 17, no. 5, p. 859, 28 Feb 2025.

[18] F. Juul, G. Vaidean and N. Parekh, "Ultra-Processed Foods and Cardiovascular Diseases: Potential Mechanisms of Action," Advances in Nutrition, vol. 12, no. 5, pp. 1673-1680, 1 Sep 2021.

[19] A. M. Shah, N. Tarfeen, H. Mohamed and Y. Song, "Fermented Foods: Their Health-Promoting Components and Potential Effects on Gut Microbiota," Fermentation, vol. 9, no. 2, p. 118, 26 Jan 2023.

[20] A. Mukherjee, S. Breseige, E. Dimidi, M. L. Marco and P. D. Cotter, "Fermented Foods and Gastrointestinal Health: Underlying Mechanisms," Nature Reviews Gastroenterology and Hepatology, vol. 21, no. 4, pp. 248-266., Apr 2025.

[21] A. Ahmad, V. Ahmad, M. A. Zamzami, H. Chaudhary, O. A. Baothma, S. Hosawi, M. Kashif, M. S. Akhtar and M. J. Khan, "Introduction and Classification of Natural Polyphenols," Polyphenols-Based Nanotherapeutics for Cancer Management, pp. 1-6, 2021.

[22] A. Winiarska-Mieczan, M. Kwiecien, K. Jachimowicz-Rogowska, J. Donaldson, E. Tomaszewska and E. Baranowska-Wojcik, "Anti-Inflammatory, Antioxidant, and Neuroprotective Effects of Polyphenols-Polyphenols as an Element of Diet Therapy in Depressive Disorders," International Journal of Molecular Sciences, vol. 24, no. 3, p. 2258, 2023.

[23] P. Perrone and S. D'Angelo, "Gut Microbiota Modulation Through Mediterranean Diet Foods: Implications for Human Health," Nutrients, vol. 17, no. 6, p. 948, 8 Mar 2025.

[24] N. S. AlAufi, Y. M. Chan, M. I. Waly, Y. S. Chin, B. N. Mohd-Yusof and N. Ahmad, "Application of Mediterranean Diet in Cardiovascular Diseases and Type 2 Diabetes Mellitus: Motivations and Challenges," Nutrients, vol. 14, no. 13, p. 2777, 5 Jul 2022.

[25] S. Del-Pozo, S. Gomez-Martinez, L. E. Diaz, E. Nova, R. Urrialde and A. Marcos, "Potential Effects of Sucralose and Saccharin on Gut Microbiota: A Review," Nutrients, vol. 14, no. 8, p. 1682, 18 Apr 2022.

[26] X. Ma, F. Nan, H. Liang, P. Shu, X. Fan, X. Song, Y. Hou and D. Zhang, "Excessive Intake of Sugar: An accomplice of Inflammation," Frontiers in Immunology, vol. 13, 31 Aug 2022.

[27] D. Cohen and C. Sapire, Fuel Up: Harness the Power of Your Blender and "Cheat" Your Way to Good Health, Hay House, Inc., 2024.

[28] S. G. Sorboni, H. S. Moghaddam, R. Jafarzadeh-Esfehani and S. Soleimanpour, "A comprehensive review on the role of the gut microbiome in human neurological disorders," Clinical Microbiology Reviews, vol. 35, no. 1, 19 Jan 2022.

[29] N. Al-Habsi, M. Al-Khalili, S. A. Haque, M. Elias, N. A. Olqi and T. Al-Uraimi, "Health Benefits of Prebiotics, Probiotics, Synbiotics, and Postbiotics," Nutrients, vol. 16, no. 22, 19 Nov 2024.

[30] T. K. Das, S. Pradhan, S. Chakrabarti, K. C. Mondal and K. Ghosh, "Current Status of Probiotic and Related Health Benefits," Applied Food Research, vol. 2, no. 2, 1 Dec 2022.

[31] R. Huang, F. Wu, Q. Zhou, W. Wei, J. Yue, B. Xiao and Z. Luo, "Lactobacillus and Intestinal Diseases: Mecahnisms of Action and Clinical Applications," Microbiological Research, vol. 260, 1 Jul 2022.

[32] P. Portincasa, L. Bonfrate, M. Vacca, M. De-Angelis, I. Farella, E. Lanza, M. Khalil, D. Q. Wang, M. Sperandio and A. Di-Ciaula, "Gut Microbiota and Short Chain Fatty Acids: Implications in Glucose Homeostasis," International Journal of Molecular Sciences, vol. 23, no. 3, p. 1105, 2022.

[33] E. Simon, L. F. Calinoiu, L. Mitrea and D. C. Vodnar, "Probiotics, Prebiotics, and Synbiotics: Implications and Beneficial Effects Against Irritable Bowel Syndrome," Nutrients, vol. 13, no. 6, p. 2112, 20 Jun 2021.

[34] N. Anand, V. R. Gorantla and S. B. Chidambaram, "The Role of Gut Dysbiosis in the Pathophysiology of Neuropsychatric Disorders," Cells, vol. 12, no. 1, pp. 1-54, 23 Dec 2022.

[35] A. R. Chavan, A. K. Singh, R. K. Gupta, S. P. Nakhate, B. J. Poddar, V. V. Gujar, H. J. Purohit and A. A. Khardenavis, "Recent Trends in the Biotechnology of Functional Non-Digestible Oligosaccharides with Prebiotic Potential," Biotechnology and Genetic Engineering Reviews, vol. 39, no. 2, pp. 465-510, 2023.

[36] L. Liu, Q. Li, Y. Yang and A. Guo, "Biological Function of Short-Chain Fatty Acids and Its Regulation on Intestinal Health of Poultry," Frontiers in Veterinary Science, 18 Oct 2021.

[37] M. M. Araujo and P. B. Botelho, "Probiotics, Prebiotics, and Synbiotics in Chronic ConstipationL Outstanding Aspects to Be Considered for the Current Evidence," Frontiers in Nutrition, 8 Dec 2022.

[38] S. A. M. Saghir and F. S. Al-Suede, "Synergistic Efficacy and Mechanism of Probiotics and Prebiotics in Enhancing Health Impcat," Microbial Bioactives, vol. 7, no. 1, p. 1, 2024.

[39] S. Janiad and K. Rehman, "Microbiome-Targeted Therapies: Enhancing Resilience in Metabolic Disorders.," in Human Microbiome: Techniques, Strategies, and Therapeutic Potential, Singapore, Springer Nature Singapore, 2024, pp. 401-436.

[40] M. Van-Hul, A. M. Neyrinck, A. Everard, A. Abot, L. B. Bindels, N. M. Delzenne, C. Knauf and P. D. Cani, "Role of the Intestinal Microbiota in Contributing to Weight Disorders and Associated Cornorbidities," Clinical Microbiology Reviews, vol. 37, no. 3, 12 Sep 2024.

[41] C. Caffaratti, C. Plazy, G. Mery, A. R. Tidjani, F. Fiorini, S. Thiroux, B. Toussaint, D. Hannani and A. Le-Gouellec, "What We Know So Far About the Metabolite-Mediated Microbiota-Intestinal Immunity Dialogue and How to Hear the Sound of This Crosstalk," Metabolites, vol. 11, no. 6, p. 406, 21 Jun 2021.

[42] J. Maiuolo, R. M. Bulotta, S. Ruga, S. Nucera, R. Macri, F. Scarano, F. Oppedisano, C. Carresi, M. Gilozzi, V. Musolino and R. Mollace, "The Postbiotic Properties of Butyrate in the Modulation of the Gut Miccrobiota: The Potential of Its Combinatoin with Polyphenols and Dietary Fibers," International Journal of Molecular Sciences, vol. 25, no. 13, p. 6871, 2024.

[43] F. Cristofori, V. N. Dargenio, C. Dargenio, V. L. Miniello, M. Barone and R. Francavilla, "Anti-Inflammatory and Immunomodulatory Effects of Probiotics in Gut Inflammation: A Door to the Body," Frontiers in Immunology, 26 Feb 2021.

[44] Y. Bourebba, K. Marycz, M. Mularczyk and L. Bourebaba, "Postbiotics as Potential New Therapeutic Agents for Metabolic Disorders Management," Biomedicine & Pharmacotherapy, vol. 153, 2022.

[45] S. Gul, A. Sattar, A. Akram, A. Waheed, M. Islam, U. Latif, I. Khaliq, H. Imtiaz, S. Majeed and I. Muzammil, "Harnessing the Power of Probiotics and Prebiotics: A Comprehensive Guide to Gut Health and Beyond," Complementary and Alternative Medicine: Prebiotics and Probiotics, p. 253, 2024.

[46] M. L. Marco, M. E. Sanders, M. Ganzle, M. C. Arrieta, P. D. Cotter, L. De-Vuyst, C. Hill, W. Holzapfel, S. Lebeer, D. Merenstein and G. Reid, "The International Scientific Association for Probiotics and Prebiotics (ISAPP) Consensus Statement on Fermented Foods," Nature Reviews Gastroenterology & Hepatology, vol. 18, no. 3, pp. 196-208, 2021.

[47] T. Kalogerakou and M. Antoniadou, "The Role of Dietary Antioxidants, Food Supplementes and Functional Foods for Energy Enhancement in Healthcare Professionals," Antioxidants, vol. 13, no. 12, p. 1508, 2024.

[48] P. Zhou, C. Chen, S. Patil and S. Dong, "Unveiling the Therapeutic Symphony of Probiotics, Prebiotics, and Postbiotics in Gut-Immune Harmony," Frontiers of Nutrition, vol. 11, 2024.

[49] M. Afzaal, F. Saeed, Y. A. Shah, M. Hussain, R. Rabail, C. T. Sool, A. Hassoun, M. Pateiro, J. M. Lorenzo, A. V. Rusu and R. M. Aadil, "Human Gut Microbiota in Health and Disease: Unveiling the Relationship," Frontiers in Microbiology, 26 Sep 2022.

[50] M. Eissa, "The Gut Microbiome: A Potential Therapeutic Path in Complementary Medicine," Journal of Research in Complementary Medicine, vol. 3, no. 1, p. 55, 2024.

[51] A. Khoruts, C. Staley and M. J. Sadowsky, "Faecal Microbiota Transplantation of Clostridioides Difficile: Mechanisms and Pharmacology," Nature Reviews Gastroenterology & Hepatology, vol. 18, no. 1, pp. 67-80, 2021.

[52] J. E. Markantonis, J. T. Fallon, M. R and M. Z. Alam, "Clostridioides Difficile Infection: Diagnosis and Treatment Challenges," Pathogens, vol. 13, no. 2, p. 118, 27 Jan 2024.

[53] N. Wu, L. X. H. Ma, X. Zhang, B. Liu, Wang, Y, Q. Zheng and X. Fan, "The Role of the Gut Microbiota and Fecal Microbiota Transplantation in Neuroimmune Diseases," Frontiers in Neurology, 1 Feb 2023.

[54] D. Y. Kim, S. Y. Lee, J. Y. Lee, T. W. Whon, J. Y. Lee, C. O. Jeon and J. W. Bae, "Gut Microbiome Therapy: Fecal Microbiota Transplantation vs Live Biotherapeutic Products," Gut Microbes, vol. 16, no. 1, 31 Dec 2024.

[55] K. Dixit, D. Chaudhari, D. Dhotre, Y. Shouche and S. Saroj, "Restoration of Dysbiotic Human Gut Microbiome for Homeostasis," Life Sciences, p. 278, 1 Aug 2021.

[56] M. T. Nelson, M. R. Charbonneau, H. G. Coai, M. J. Castillo, C. Holt, E. S. Greenwood, P. J. Robinson, E. A. Merrill, D. Lubkowicz and C. A. Mauzy, "Characterization of an Engineered Live Bacterial Therapeutic for the Treatment of Phenylketonuria in a Human Gut-On-A-Chip," Nature Communications, vol. 12, no. 1, p. 2805, 2021.

[57] G. Lagoumintzis and G. P. Patrinos, "Triangulating Nutrigenomics, Metabolomics, and Microbiomics Toward Personalized Nutrition and Healthy Living," Human Genomics, vol. 17, no. 1, p. 109, 2023.

[58] C. Li, "Understanding Interactions Among Diet, Host and Gut Microbiota for Personalized Nutrition," Life Sciences, vol. 312, no. 1, 2023.

[59] P. Chen, C. Yang, K. Ren, M. Xu, C. Pan and X. X. L. Ye, "Modulation of Gut Microbiota by Probiotics to Improve the Efficacy of Immunotherapy in Hepatocellular Carcinoma," Frontiers in Immunology, vol. 15, 2024.

[60] A. Latif, A. Shehzad, S. Niazi, A. Zahid, W. Ashraf, W. W. Iqbal, A. Rehman, T. Riaz, R. M. Aadil, I. M. Khan, F. Ozogul, J. M. Rocha, T. Esatbeyoglu and S. A. Korma, "Probiotics: Mechanism of Action, Health Benefits and Their Applications in Food Industries," Frontiers in Microbiology, vol. 14, no. 15, 2023.

[61] S. Ferrari, S. Mule, F. Parini, R. Galla, S. Ruga, G. Rosso, A. Brovero, C. Molinari and F. Uberti, "The Influence of the Gut-Brain Axis on Anxiety and Depression: A Rview of the Literature on the Use of Probiotics," Journal of Traditional and Complementary Medicine, 2024.

[62] D. J. Lynn, S. C. Benson, M. A. Lynn and B. Pulendran, "Modulation of Immune Responses to Vaccination By the Microbiota: Implications and Potential Mechanisms:," Nature Reviews Immunology, vol. 22, no. 1, pp. 33-46, 2022.

[63] S. Rogers, A. Charles and R. M. Thomas, "The Prospect of Harnessing the Microbiome to Improve Immunotherapeutic Response in Pancreatic Cancer," Cancers, vol. 15, no. 24, 2023.

[64] G. Chatterjee, S. Negi, S. Basu, J. Faintuch, A. O'Donovan and P. Shukla, "Microbiome Systems Biology Advancements for Natural Wellbeing," Science of The Total Environment, vol. 838, 10 Sep 2022.

[65] E. C. Oldfield-IV, E. C. Oldfield-III and D. A. Johnson, "Clinical Update for the Diagnosis and Treatment of Clostridium Difficile Infection," World Journal of Gastrointestinal Pharmacology and Therapeutics, vol. 5, no. 1, 2014.

[66] E. Zikou, C. Koliaki and K. Makrilakis, "The Role of Fecal Microbiota Transplantation (FMT) in the Management of Metabolic Diseases in Humans: A Narrative Review," Biomedicines, vol. 12, no. 8, p. 1871, 16 Aug 2024.

[67] L. Flandroy, T. Poutahidis, G. Berg, G. Clarke, M. C. Dao, E. Decaestecker, E. Furman, T. Haahtela, S. Massart, H. Plovier and Y. Sanz, "The Impact of Human Activities and Lifestyles on the Interlinked Microbiota and Health of Humans and of Ecosystems," Science of the Total Environment, vol. 627, pp. 1018-1038, 15 Jun 2018.

[68] V. Fusco, F. Fanelli and D. Chieffi, "Authenticity of Probiotic Foods and Dietary Supplements: A Pivotal Issue to Address," Critical Reviews in Food Science and Nutrition, vol. 62, no. 25, pp. 6854-6871, 1 Sep 2022.

[69] M. Karimi, N. Shirsalimi, Z. Hashempour, H. Salehi-Omran, E. Sedighi, F. Beigi and M. Mortezazadeh, "Safety and Efficacy of Fecal Microbiota Transplantation (FMT) as a Modern Adjuvant Therapy in Various Diseases and Disorders: A Comprehensive Literature Review," Frontiers in Immunology, vol. 15, 2024.

[70] R. R. Dietert, "Microbiome First Approaches to Rescue Public Health and Reduce Human Suffering," Biomedicines, vol. 9, no. 11, p. 1581, 2021.

[71] M. K. Gupta, V. Balod, A. D. Tripathi, A. Agarwal and N. P. Nirmal, "The Importance of Labeling and Certification: Ensuring Quality and Transparency," in Unleashing the Power of Functional Foods and Novel Bioactives, Academic Press, 2025, pp. 449-465.

[72] L. D. Diaz, V. Fernandea-Ruiz and M. Camara, "An International Regulatory Review of Food Health-Related Claims in Functional Food Products Labeling," Journal of Functional Foods, vol. 68, 2020.

[73] K. H. Chuong, D. R. Mack, A. Stintzi and K. C. O'Doherty, "Human Microbiome and Learning Healthcare Systems: Integrating Research and Precision Medicine for Inflammatory Bowel Disease," Omics: A Journal of Integrative Biology, vol. 22, no. 2, pp. 119-126, 2018.

[74] M. O. Yaqub, A. Jain, C. E. Joseph and L. K. Edison, "Mircobiome-Driven Therapeutics: From Gut Health to Precision Medicine," Gastrointestinal Disorders, vol. 7, no. 1, p. 7, 2025.

[75] J. E. Wilkinson, E. A. Franzosa, C. Everett, C. Li, F. B. W. D. F. Hu, M. Song, A. T. Chan and E. Rimm, "A Framework for Microbiome Science in Public Health," Nature Medicine, pp. 766-774, 27 May 2021.

[76] Ifunanya Emmanuella Ezeumeh, Matthew O. Akindoyin, Adepeju Olowookere, Osinubi Morenike, Temitope Ruth Folorunso, & Ilori Gbenga John. (2024). Advancements In Biotechnology For Early Disease Detection: Integrating Biosensors And Genomic Technologies To Improve Health Outcomes. International Journal Of Advanced Research In Engineering And Technology (IJARET), 15(5), 34-41.