Prebiotics and Postbiotics: The synergistic potential in regulating the gut microbiota and host health

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Abstract. Using prebiotics, probiotics and their synergistic combination to perform therapeutic operations on intestinal microflora has become a potential way to prevent and control chronic metabolic diseases and inflammatory diseases. Indigestible prebiotics (selectively stimulating beneficial bacteria, and post-production elements (effective metabolites or components formed by microbial activities) will all help to reshape the intestinal environment and adjust the immune response and metabolic status of the host. This account brings together the latest research on various compounds, including inulin, arabinoxylan oligosaccharide, muramyl dipeptide, extracellular vesicle and plant-derived polysaccharide, all of which show that these substances can promote SCFA to strengthen the integrity of intestinal barrier and regulate inflammation. The synbiotic method of combining prebiotics and probiotics or the products produced by these interactions have an amplification effect on regulating microbial communities and host pathways. After summarizing their action mechanisms and applications, the transformation potential of implementing nutritional strategies for microorganisms is highlighted.

Keywords: Prebiotics, Postbiotics, gut, microbiota.

1. Introduction

The human intestinal microflora consists of trillions of microorganisms, which play an important role in digestion, immunity and systemic metabolic regulation. This destruction of microbial balance-ecological imbalance-is related to obesity, diabetes, inflammatory bowel disease (IBD) and neurodegenerative diseases. Targeting microorganisms through dietary components provides a new safe treatment strategy, among which prebiotics, probiotics and their combination with probiotics (synbiotics) have attracted great attention.

Although probiotics have been widely studied, new research shows the benefits of prebiotics and probiotics, and even better than probiotics in some aspects. Probiotics are indigestible compounds, which can stimulate the number and vitality of beneficial intestinal microorganisms, while probiotics are products or metabolic by-products produced by inactive bacteria, which can also have an impact on health alone without live bacteria, directly affecting host signal pathway, inflammation and intestinal barrier function. Recent studies have also confirmed that the combination of these substances will have a synergistic effect. However, the current problem is: how to find the most effective bioactive components? Understand their working principle and ensure their reproducibility under clinical conditions.

This review summarizes the recent experimental results to evaluate how various prebiotics and prebiotic interventions affect the composition of intestinal microflora, metabolic pathways and host health results, and to provide practical insights for future nutrition and development.

2. Prebiotics

2.1. Definition

Prebiotics are defined as a component of selective fermentation, which will change the composition or activity of gastrointestinal microflora, and then have beneficial effects on the host [1][2]. Different from probiotics composed of living bacteria, prebiotics are indigestible food parts, mainly dietary fibers and oligosaccharides, which arrive in the colon intact and become the basis for the growth of beneficial intestinal microorganisms [2][3]. Their influence comes from microbial fermentation and subsequent metabolites, especially short-chain fatty acids [2].

2.2. Types of Prebiotics

Common prebiotics include fructooligosaccharides (FOS), inulin, galactooligosaccharides (GOS), β-mannan oligosaccharides (β-MOS), arabinoxylan oligosaccharides (AXOS) and resistant starch [1][2][3]. Emerging sources of prebiotics are human milk oligosaccharides (HMOs) [4][5], as well as various plant-derived polysaccharides such as astragalus polysaccharides (APS) [6][7], ganoderma lucidum polysaccharides [8] and carbohydrates extracted from ginseng. These prebiotics differ in structure and fermentation characteristics and exert specific effects on the composition of intestinal microbial populations.

2.3. Biological mechanisms of prebiotics in gut microorganisms

The main mechanism of prebiotics is that they selectively promote beneficial bacteria, including Bifidobacterium, lactobacillus, Akkermansia and Enterobacter faecalis [1][2][4]. These bacteria can enhance intestinal barrier function, regulate immune response and inhibit pathogen colonization; These microorganisms have anti-inflammatory properties for fatty acids such as butyrate, propionate and acetate produced by prebiotic fermentation [2][3] as energy sources of colon cells to regulate glucose and lipid metabolism and affect satiety hormones [2][9].

2.4. Interaction with Probiotics

As the energy source of probiotics, prebiotics enhance their viability and metabolic function [10][11]. This synergistic effect can improve the output and immune regulation of SCFA. For example, inulin promotes the growth of Lactobacillus [2] [3], and WBAX promotes the transformation of tryptophan into immunomodulatory ligand by Lactobacillus reuteri[10].

2.5. Microbial and Metabolic Effects

Some studies support the microbial and metabolic specificity of prebiotics. Inulin-type fructan (itf) can increase the number of bifidobacteria in obese people and reduce endotoxemia [2]. AXOS from wheat bran can strengthen intestinal motility and increase the number of Bifidobacterium and Lactobacillus [1]. GOS can adjust the microbial balance when the flora is out of balance and affect the glycosylation mode of mucosa. Plant polysaccharides such as APS enrich SCFA-producing bacteria and down-regulate pre-inflammatory pathways, such as NF-κB [6][7]. These microbial changes have turned into clinical benefits, including improving intestinal regularity [1], optimizing blood sugar control [3], reducing systemic inflammation [2][7] and improving mental health by regulating intestinal brain axis [9].

2.6. Clinical Applications

Probiotics are considered as a drug to control neuropsychiatric diseases such as obesity [3], metabolic syndrome [6][7], inflammatory bowel disease [7] and even depression. However, its effect depends on individual microbial composition, diet environment and dosage [1][2]. Personalized prebiotic formula may be the next frontier of intestinal targeted nutrition therapy [11].

3. Postbiotics

3.1. Definition

Probiotics are inactive bacterial products or metabolic byproducts derived from probiotics, which are beneficial to the host [12][13] [14][15]. Including cell wall fragments (such as peptidoglycan and lipoteichoic acid) [16], short-chain fatty acids (scfa) [17], microbial metabolites (such as indole derivatives, lactic acid, protein and EVs [12], etc. Unlike probiotics, metazoans do not need to survive, settle down or survive through the gastrointestinal tract, so they are more stable and safer for some people [15][18].

3.2. Types of Postbiotics

Biostatin acts through several ways, and SCFAs interacts with G protein-coupled receptors (GPR41, GPR43) like butyrate to regulate immune signals and intestinal barrier function [17]. Indole derivatives such as indole-3-lactic acid (ILA) and indole-3-propionic acid (IPA) activate aromatic hydrocarbon receptor (AhR), thus promoting mucosal healing and the production of IL-22. Peptidoglycan components such as muramyl dipeptide (MDP) will trigger GLP-1 secretion and improve glucose regulation after binding with intracellular receptors such as NOD2 [16], and enteroviruses can release bioactive substances and then affect the intestine [12].

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3.4. Interaction with Probiotics

Probiotics represent the metabolism and structural output of probiotic activity [13][14][15]. They are different from living microorganisms because they are stable, safe and active functional units, and there is no need to establish a colony. Their effects often reflect their parental strains [18].

Probiotics have functions and are related to probiotics because they are metabolites produced by microorganisms. Although probiotics provide benefits through settlement and competitive exclusion, they are the downstream bioactive substances of these activities, which enables those who avoid using probiotics for safety reasons (such as newborns, the elderly or people with impaired immune system) to use probiotics [13].

3.5. Microbial and Functional Outcomes

Representative examples include mucin Akkermansia and EVS of Lactobacillus species [12] [13], which can reduce obesity-related inflammation, improve intestinal barrier integrity and promote liver health [19]. Heat-inactivated strains such as Bifidobacterium bifidum B1628 [18] and Lactobacillus argentinus BBB001 [14] can improve the composition of intestinal microflora [18], reduce the level of inflammatory markers [14], and improve the intestinal immune tolerance [14]; MDP has been proved to stimulate the secretion of GLP-1 in normal blood glucose model, but it is not effective in hyperglycemia environment, which means an environment-dependent mechanism [16].

3.6. Clinical Applications

Postnatal preparations are very valuable in high-risk groups (infants, the elderly, immunodeficiency) [13][18]. Their support for IBD [18][19], NAFLD [19], cancer treatment and mental health, immune homeostasis, intestinal repair and general health.[9].

Biocin is increasingly used to treat IBD, metabolic diseases, neuroinflammation and muscular atrophy. Because of its stable nature, it is easier to store, transport and make it into supplements and functional foods [15][20]. But more research is needed to determine the definition, dosage and long-term effect [10][19].

4. Synergistic Effects and Synbiotics

The combination of prebiotics and probiotics-synbiotics-takes advantage of the advantages of these two components [5][10][11]. In this case, prebiotics are used as substrates to support colonization, activity and survival of co-administered probiotic strains [11]. This synergy amplifies the production of beneficial metabolites, such as scfa [10], bile acids and AhR ligands [10], thus improving the results of the host.

From the mechanism point of view, synbiotics create a good environment for probiotics, especially in the destroyed microbial community [11]. The existence of specific prebiotics ensures the metabolic competitiveness of probiotics, and the probiotic compounds produced by these microbial activities further promote mucosal immunity and metabolic regulation [5][10].

Recent studies have shown this synergistic effect. The fusion of wheat gluten arabinoxylan (WBAX) with Lactobacillus reuteri WX-94 is beneficial to the process of microbial transformation of tryptophan into AhR ligand, which will promote the colon to produce IL-22 and repair the intestinal barrier [10]. In some models, the post-organism derived from WBAX itself surpasses the synthetic organism in anti-inflammatory effect. This shows that the effect of concentrating microbial metabolites is very strong [10]. Another example is Aunulife—, a compound containing prebiotics and metazoans, which can better improve obesity and related indicators compared with the use of these two components alone [20].

Symbiosis strategy also has a good prospect for infant intestinal development [5] regulating the intestinal-brain axis system [11] and strengthening the resistance of immune system. Their applications in functional foods and clinical nutrition are also expanding, but it is still difficult to find the best combination of strains and substrates [11] to understand the interaction between hosts and microorganisms and determine a clear control approach [11].

The co-deployment of prebiotics, probiotics and probiotics gives a powerful tool kit for health intervention against microorganisms, and continuous research and update will be the key to tap the full therapeutic potential.

5. Safety, Regulation, and Future Prospects

Although probiotics may bring risks to vulnerable people [13][18], probiotics and prebiotics are usually safer and more stable [15]. The definition of supervision and quality control are different all over the world and need to be coordinated [10][19].

Future research should prioritize:

Standardization of postbiotic classification and functional assays [10][19].

Personalized synbiotic formulations [11].

Mechanistic elucidation via omics approaches [11].

Long-term clinical trials on chronic disease endpoints [10][20].

6. Conclusions

Prebiotics and probiotics are powerful catalysts for restoring intestinal flora and optimizing host health. These components can change the composition of microbial groups, promote the increase of beneficial metabolites, and improve metabolism and immune homeostasis. In this respect, prebiotics specifically enhance the output of useful bacteria and related metabolites, and in terms of direct functional impact, probiotics can adjust the properties such as immunity, metabolism and maintaining barrier integrity. Synbiotics strategy strengthens the interdependence by coordinating the role of microecology, but some limitations now include the lack of clear process mechanism, the variable state of research design and the inconsistency of supervision. Future research needs to find ways to narrow these differences by controlled experiments and machinery. In the end, the nutrition dominated by microbiota brings many hopes for personalized medical care, chronic disease management and preventive health care. We are also glad to see that this review can help more people understand the role of prebiotics and probiotics in intestinal microflora and improve their understanding of intestinal microflora health.

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