Gut Microbiota and Weight Regulation: The Role of Probiotic and Prebiotic Interventions

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Abstract

The comprehensive overview of this article delves into the intricate relationship between gut microbiota, weight regulation and the importance of dietary interventions, particularly probiotics and prebiotics. The diversity of microbiota in gut highlights its critical role in maintaining general health and aiding in weight management under the influence of macronutrients (proteins, carbohydrates and fats) which affect the microbiota composition along with the essential micronutrients including vitamins and minerals. Prime functions such as vitamin metabolism, SCFA production, polyphenols, and butyrate production are discussed along with the effect of sleep, stress and antibiotics upon the gut microbiota extending the discussion to the pathogen protective capabilities. Additionally, the article explores the dynamic interplay between microbiota and obesity due to disruption of gut-brain relationship leading to the alteration of gut microbes. Correlation between gut microbiota and weight loss is studied by focusing on different dietary practices, importance of probiotics and prebiotics and different foods having a positive impact on the microbiota.

Keyword: Weight management, Microbiome, Probiotic, Prebiotics, Micro and macro-nutrients.

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Introduction

The debate about microbiota highlights the influence of internal environment on human health. Human GI tract hosts a dense microbial ecosystem with about 100 trillion bacteria (Passos & Moraes-Filho, 2017) which makes human and their microbes "superorganisms" (Thursby & Juge, 2017). Childbirth mode, lifestyle choices, drug and prescription medications (Hasan & Yang, 2019), growing older, and other environmental factors all have an influence on the variety and composition of the gut microbiome (Dong & Gupta, 2019).

A healthy gut microbiome produces short chain fatty acids, nutrients and antioxidants along with potentially harmful substances (Liu et al., 2021). These affect gene expression, immunity and metabolism thus, playing an important role in digestion and energy regulation. Gut microbiota mainly includes six phyla: *Firmicutes, Bacteroidetes, Actinobacteria, Proteobacteria, Fusobacteria*, and *Verrucomicrobia*, with *Firmicutes* and *Bacteroidetes* being predominant (Hou et al., 2022).

A disruption in gut flora is linked to various human infections and conditions, including obesity, inflammatory bowel diseases (IBD) (Nishino et al., 2018), diabetes, autoimmune diseases (Chu et al., 2017), allergies, and cardiovascular disease. Digestive problems and increased satiety can lead to obesity. Changes in gut bacteria have been linked to infections and inflammatory diseases, potentially affecting metabolism and energy balance (Nieuwdorp et al., 2014). Human gut microbes influence nutrient consumption and storage, affecting host physiology. Despite variations in individual gut microbiota due to lifespan changes, the overall activities of gut microbes remain similar among individuals.

The impact of the gut microbiome on wellness has been a major topic of interest research for many years since sufficient gut microbiota and probiotic supplements have favourable impacts on a number of health conditions (Sánchez et al., 2017). The majority of research on overweight and obese persons demonstrates dysbiosis with decreased variety. The gut microbiota appears to be involved in the onset and progression of obesity (Aoun et al., 2020). Research indicates that dietary changes can quickly alter the microbiome within a day, highlighting nutrition's role in its formation. This suggests that modifying microbial composition through diet could offer significant therapeutic benefits.

Our eating habits include a variety of foods from plants and animals that provide essential nutrients like proteins, fats, carbohydrates, vitamins, and minerals for energy and growth. Our diet also influences the composition of gut microbiota, which can be modulated by changing eating patterns and adding probiotics and prebiotics (Houghton et al., 2016).

Composition and Diversity

Diet and host genetics influence gut microbiota composition. Various chemical, dietary, and immune factors can change its structure and density. The gastrointestinal tract's high levels of chemicals and oxygen support only rapidly growing facultative anaerobes capable of adhering to epithelium or mucus.

Many microorganisms, notably bacteria, yeast, and viruses, contribute to the gut microbiota. The most prevalent gut microbial phyla are *Proteobacteria, Bacteroidetes, Firmicutes, Actinobacteria, Fusobacteria*, and *Verrucomicrobia* as shown in figure 1. *Bacteroidetes* making up most of the gut flora (Aoun et al., 2020). The *Firmicutes* phylum has approximately 200 unique genera, including *Clostridium, Enterococcus, Lactobacillus, Bacillus*, and *Ruminicoccus*. *Clostridium* genera constitute 95 per cent of the *Firmicutes* phylum. Bacteroidetes are made up of several main genera, including *Bacteroides* and *Prevotella*. Actinobacteria is a smaller phylum, and it is largely represented by the *Bifidobacterium* genus. The sole known member of the *Verrucomicrobia* phylum is *Akkermansia muciniphila* (Thursby & Juge, 2017).

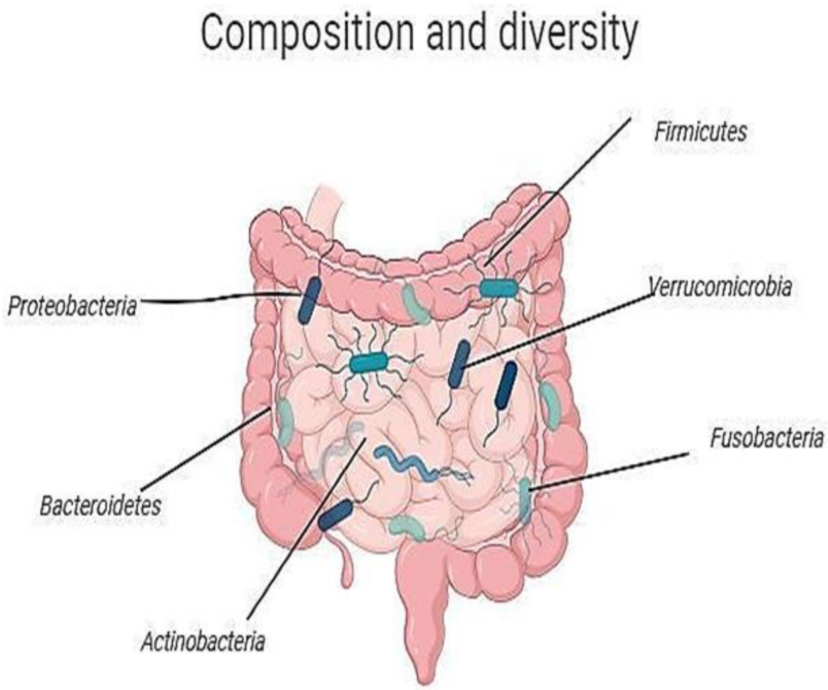

Fig. 1: Composition and diversity of microorganism in gut microbiota.

In humans, most gut microbiota is anaerobic and located in mucosal areas like the buccal cavity and GI tract. This microbiota varies in composition and function, influenced by factors such as pregnancy, age, antibiotic use, pH, oxygen levels, and substrate availability. Additionally, the method of delivery at birth impacts early-life gut microbiota development. Vaginal delivery results in a microbiota composition mainly consisting of *Lactobacillus* and *Prevotella*, while cesarean section results in a prevalence of *Streptococcus, Corynebacterium,* and *Propionibacterium* (Hasan & Yang, 2019).

The correlation between disease and reduced diversity indicates that a species-rich intestinal environment is more resilient, as functionally similar bacteria can compensate for missing species. Thus, greater variety is a key sign of a "healthy gut" (Valdes et al., 2018).

Factors Influencing Gut Microbiota Composition

Dietary Macronutrients

Dietary macronutrients such as carbohydrates, fats, and protein have a substantial influence on the diversity of gut microbiota (discussed in table 1). Digestible carbohydrates like simple sugars can increase opportunistic bacterial growth, while complex carbs like dietary fiber are beneficial for gut health. Animal protein can lead to digestive issues, while plant-based protein stimulates the production of beneficial SCFAs. Saturated fats from animals may have a detrimental effect on gut health, while plant-based unsaturated fats promote a healthier gut microbiota. Quality and saturation of fats also play an important role in gut health (Ramos & Martín, 2021).

Dietary Micronutrients

Essential micronutrients, nearly 30 vitamins and minerals that the body can't produce in sufficient amounts, significantly impact gut microbiota. For example, a vitamin A deficiency reduces beneficial bacteria and increases harmful ones, while vitamins A and E promote beneficial bacteria growth. Vitamin D may also support beneficial bacteria development. In contrast, high iron intake can negatively affect gut health. Vitamin C's antioxidant properties improve gut microbiota, and polyphenols have anti-inflammatory effects. Magnesium promotes beneficial bacteria and inhibits pathogens, whereas calcium's effects vary. Selenium enhances certain beneficial bacteria, zinc deficiency alters gut microbiota, and iodine interacts differently with low-fat and high-fat diets as shown in Table 2.

Sleep: Persistent lack of sleep increased food consumption and caused a reversible shift in gut microbiota, resulting in increased *Lactobacillacae* and *Ruminococcus* strains (Liu et al., 2021). Sleep deprivation disrupts the circadian cycle, which has the ability to harm the flora and play a role in obesity.

Stress: The HPA axis can affect gut microbiota composition; with stress leading to reduced *lactobacilli* and *Bacteroides spp.* and increased *Clostridium spp*. Chronic stress may disrupt the intestinal barrier and influence the gut's effect on HPA activity through neural signals, short-chain fatty acids, epigenetics, barrier permeability regulation, or microglial cell activation (Sudo, 2016).

Antibiotics: Antibiotics significantly impact the microbiota, leading to reduced species diversity, loss of important species, shifts in metabolism, increased vulnerability to invasion, and antibiotic resistance (Altveş et al., 2020).

Table 1: Effect of dietary macronutrient compounds on gut composition

Sr.	Dietary macronutrients compounds	Gut composition	
		Increase	Decrease
1.	Carbohydrate (Seo et al., 2020)	proliferation of opportunistic pathogens	SCFAs production
	• Digestible carbohydrates	*(E.coli, streptococcus)*	
		stimulate SCFAs production	Opportunistic pathogens
	• Complex Indigestible carbohydrates	*Bifidobacterium*	
		Lactobacallus	
		Akkermansia	
		Fecalibacterium	
		Roseburia	
		Bacteroides	
		Prevotella	
		Clostridium	
		Ruminococcus	
2.	Protein (Kostovcikova et al., 2019)	*Enterococcus*	*Bifidobacterium*
	• Animal protein	*Streptococcus*	SCFAs production
		Peptostreptococcus	
		Bifidobacteriaceae	
	• Plant protein	*Desulfovibrionaceae*	
		Lactobacillaceae	
		Lachnospiraceae	---------
		Erysipelotrichaceae	
		stimulating SCFAs production	
3.	Fats	*Bilophila*	*Bifidobacterium*
	• Saturated fat (Moszak et al., 2020)		*Bacteroidetes*
			Prevotella
			Lactobacillus
	• Unsaturated fat (Muralidharan et al., 2019)	*Bifidobacterium*	
		Roseburia	
		Faecilibacterium	

Key Functions and Health Implications of Gut Microbiota

Healthy microbiota regulates mucosal barrier, nutrient absorption and provides immunity boost. The connection with the brain through different pathways elaborates crucial role in general health. Known to be the “second brain”, the gut controls the feelings of fullness and appetite (Aoun et al., 2020).

Nutrient Absorption

Vitamin Metabolism

Enzymes of gut microbiota regulate vitamin absorption. Vitamin K is produced by intestinal microbes which aids in clotting (Thursby & Juge, 2017). Secondary bile acids are formed due to gut microbiota along with production of Menaquinone, folate, cobalamin, and riboflavin for their metabolic needs, serving as vitamin K, B9, B12 and B2 in humans (Derrien & Veiga, 2017).

Short-Chain Fatty Acids (SCFAs)

SCFAs, mainly acetate, butyrate, and propionate, are produced by fermenting non-digestible fibers in the gastrointestinal (GI) tract. They influence gene expression, cell proliferation, and death, playing key roles in lipid and glucose metabolism (Thursby & Juge, 2017).

Butyrate a 4-carbon SCFA produced by *Firmicutes* and *Bacteroides*, serves as an energy source for colonocytes, promoting lipid metabolism and exhibiting anti-inflammatory and anti-cancer properties. It also enhances mucin barrier function and regulates energy balance (Liu et al., 2021, Valdes et al., 2018, Coppola et al., 2021).

Propionate results from beta-glucan fermentation in whole grains and helps regulate appetite and gluconeogenesis in the liver (Bai et al., 2021). Species linked to propionate synthesis are *Veillonella parvula*, *Bacteroides eggerthii*, *Bacteroides fragilis, Ruminococcus bromii,* and *Eubacterium dolichum* (Shimizu et al., 2018).

Acetate is produced from the fermentation of resistant starch and polysaccharides. Key producers include *Prevotella, Bifidobacterium,* and *Akkermansia muciniphila*. Acetate supports microbial growth, boosts energy metabolism, influences appetite and immune system regulation, and maintains gut barrier integrity (Nogal et al., 2021).

Table 2: Effect of dietary micronutrients compounds on gut composition

Sr.	Dietary micronutrients compounds	Gut composition	
		Increase	Decrease
1.	Vitamin A	*Bifidobacterium Lactobacillus*	
	Vitamin E	*Bifidobacterium Lactobacillus*	
	Vitamin D (Charoenngam et al., 2020)	*Bacteroides*	
		Parabacteroides	
	Vitamin C (Xu et al., 2014)	*Lactobacillus*	*E.coli*
		Bfidobacterium counts	
2.	Iron supplement (Sjödin et al., 2019)		*Bifidobacterium Lactobacillus*
3.	Polyphenols (Selma et al., 2009)	*Lactobacillus*	*Helicobacterpylori*
		Bifidobacteria	*Staphylococcus sp.*
4.	Magnesium (Pachikian et al., 2010)	*Lactobacillus*	*E. coli*
		Bifidobacteria	pathogenic strains
5.	Calcium	*ClostridiumXVIII (Trautvetter et al., 2018)*	
		Ruminococcaceae	
		Akkermansia Bifidobacterium sp. (Chaplin et al., 2016)	
6.	Phosphorus	Butyrate-producing bacteria	
		Fecalibacterium	
		Pseudoflavonifracto (Borda-Molina et al., 2016)	
7.	Selenium supplement (Zhai et al., 2018)	*Akkermansia*	*Dorea*
		Turicibacter	*Mucispirillum*
8.	Zinc supplement (Zackular et al., 2016)	*Lactobacillus sp.*	*Salmonella sp.*
9.	Iodine supplement (Shen et al., 2019)	Pathogenic microbes	*Fecalibacterium prausnizii*
	• With high fat		
		Bifidobacterium Lactobacillus Fecalibacterium	
	• With low fat	*Allobaculuum*	

Additional Metabolic Products

Trimethylamine is produced by gut flora from phosphatidylcholine and carnitine (found in meat and milk), converting in the liver to trimethylamine oxide (TMAO), which is associated with atherosclerosis and cardiovascular risk (Valdes et al., 2018). Diets high in animal protein and fat, particularly meat, increase levels of TMAO and promote genera like *Bacteroides, Alistipes,* and *Ruminococcus* while decreasing *Bifidobacterium* (Singh et al., 2017).

Indole-propionic acid (IPA), linked to fiber intake, exhibits strong antioxidant activity and may lower type 2 diabetes risks. It also inhibits amino acid production and is effective against various *mycobacteria*, including drug-resistant strains (Valdes et al., 2018).

Polyphenols, are known for their health benefits and include flavonoids and phenolic acids. They increasing beneficial bacteria like *Bifidobacterium* and *Lactobacillus*, which help protect against pathogens and reduce inflammation (Sun et al., 2018). Polyphenols, classified as prebiotics, support gut health by nourishing *Bifidobacteria* and promoting *Akkermansia muciniphila* through increased consumption of grapes or cranberries (Van Buiten et al., 2024). They also possess antioxidant and anti-inflammatory properties.

Dietary Patterns

Weight loss and gut health are influenced by a varied diet that promotes microbiome diversity and weight management. Portion sizes should align with energy output and be consumed three times a day, as eating habits shape gut flora over time (Fetissov, 2017). Irritable bowel syndrome can be managed with restricted diets such as vegan, gluten-free, and low FODMAP, which positively impact gut health (Valdes et al., 2018).

Western diet: Characterized by high consumption of processed foods, refined cereals, and high-sugar products, a high-fat dairy products, processed meats (Clemente-Suárez et al., 2023). This diet leads to a low microbial diversification and results in a reduction in *Firmicutes, Enterobacteriaceae*, and in *Bacteroidetes* and increase in *Mollicutes* (Senghor et al., 2018).

Mediterranean diet: Focuses on fruits, vegetables, whole grains, and healthy fats while minimizing sweets and red meat (Jin et al., 2019). This diet enhances microbial diversity, leading to beneficial gut bacteria and improving gut health (Merra et al., 2020).

Vegetarian diet: Plant based diet including fruits, vegetables, legumes, grains, seeds and nuts with exclusion of meat and animal products (Shen et al., 2024). *Enterobacteriaceae* reduces inflammation in vegans. High fiber content promotes *Bifidobacterium, Prevotella, Bacteroides* and *Clostridium* which break down fiber while pholyphenol boosts *Bifidobacterium* and *Lactobacillus* (Losno et al., 2021).

High-fiber diet: A high-fiber diet includes whole, unprocessed foods that are high in fiber, which include fruits, vegetables, and grains. Such a diet increases *Bifidobacteria*, Microbial diversity, and the *Firmicutes/Bacteroidetes* ratio.

High-fat diet: A high-fat diet (HFD) is one in which fats, including unsaturated and saturated, make up least 35% of total calorie intake. A diet like this results in lesser *Bacteroidetes* and more *Firmicutes*.

High-protein diet: A diet consisting of 20% protein or more from daily calorie intake. It includes meat, poultry, fish, eggs and soy. Protein digestion into peptides can alter gut microbial species such as *Bacteroidetes, Actinobacteria, Firmicutes, Proteobacteria, Roseburia, Lactobacillus, and Verrucomicrobia*. Hence, affecting gut microbial composition and diversity (Wu et al., 2022).

Gut Microbiota and Body Weight Regulation

Energy expenditure by microbes helps to understand new weight control options as they control glucose metabolism, appetite, and fat storage and affect energy metabolism. Body fat and waist circumference are negatively and positively associated with *Bacteroidetes* and *Firmicutes* respectively (Pisanu, 2021).

Microbiota and Obesity

Obesity is caused by energy imbalance, and is managed by exercise and calorie deficit. Diabetes and heart diseases are linked to obesity and imbalanced gut microbiota (Van Hul & Cani, 2023; Li et al., 2024). Gut microbiota's role in obesity has led to innovative therapies. Research on the obese gut microbiota indicates a low *Firmicutes/Bacteroidetes* ratio in obese people stated through 16S rRNA gene sequencing (Indiani et al., 2018; Liu et al., 2021). *Lactobacillus* has a species-specific effect on weight. *L. paracasei* reduces obesity, while *L. reuteri* and *L. gasseri* increase it (Liu et al., 2021). *Bacteroidetes* is linked to weight loss while obesity is correlated to *Firmicutes*. Stress affects the gut-brain axis thus, influencing obesity (Gupta et al., 2020).

Though the role of SCFAs in obesity is debated, high SCFAs in feces links to obesity as they increase appetite, fat storage, inflammation and affect circadian rhythms. Obesity relates to low SCFA levels and diversity, with country of origin as a key factor (Liu et al., 2021; Ecklu-Mensah et al., 2023).

The brain is linked with the microbiota through different routes like the gut-brain axis, which includes endocrine, immunological, and neurological pathways. The gut-brain axis influences obesity by serotonin modulation involving endocrine, immune, and neurological pathways. Genetic variation also affects diversity of microbes in obesity (Margolis et al., 2021)

Microbiota and Weight Loss

Intestinal permeability is reduced by healthy gut microbiota supporting healthy weight. Plant based diet 30g of fiber from colourful plants diversifies microbiota along with healthy fats. Nutrient absorption is affected from malnutrition due to microbiota imbalance (García-Montero et al., 2021). Certain diets reduce beneficial bacteria like *Firmicutes, Lactobacillus*, and *Bifidobacterium* (Seganfredo et al., 2017).

The *Christensenellaceae* correlates with lower weight and BMI (Waters & Ley, 2019), while *Akkermansia muciniphila* alleviates obesity and improves metabolism (Depommier et al., 2019)**.** Human investigations have revealed that *A. muciniphila* has a significant influence on metabolism. It protects against permeability issues, boosts immunity, and improves glucose homeostasis (Pitocco et al., 2020). Exercise increases beneficial bacteria like *Bifidobacteria* and *Akkermansia*, enhancing microbiota diversity, SCFA synthesis, and glucose metabolism while reducing the *Firmicutes/Bacteroidetes* ratio (Aya et al., 2021).

Modulating Gut Microbiota for Weight Management

Probiotics and prebiotics have been used to prevent and cure a variety of ailments, but they also serve a crucial role in maintaining healthy gut flora. They are frequently regarded as functional foods (Aoun et al., 2020).

Probiotics

In 2002, the FAO and WHO defined probiotics as "live microorganisms that, when administered in adequate amounts, confer a health benefit on the host" (Food & Agriculture Organization/World Health Organization Working, 2002). Various health benefits are associated with *Lactobacillus, Bifidobacterium, Bacillus, Pediococcus*, and some yeast (Soemarie et al., 2021). In a study, probiotics reduced weight gain in 20 obese men on high calorie diet for 30 days (Aoun et al., 2020).

Probiotics aid in glycemic control hence reducing weight, BMI, waist circumference and fat mass in obese people (Wang et al., 2019). They can enhance SCFA producing bacteria, lower LPS producers and reduce tissue degeneration and inflammation. Regulation of neuropeptides, gastrointestinal peptides and insulin resistance may be due to probiotics (Sorboni et al., 2022). When selecting a probiotic, consider its purpose (therapy, prevention, or treatment), suitability for children versus adults, and relevant clinical studies (Maftei et al., 2024).

Prebiotics

Prebiotics are non-metabolized food elements that pass through the bowel and are used by beneficial microbes. SCFAs like butyrate, acetate and propionate are important prebiotics (Wiese et al., 2019). Prebiotic supplements like inulin, galacto-oligosaccharides and fructo-oligosaccharides are emphasized in recent studie (Wiese et al., 2019). Inulin aids obesity control through calorie reduction due to increased peptide YY(PYY) cells by 87% (Brooks et al., 2017). GOS increases *bifidobacterium* and lowers *bacteroides spp* while FOS promotes *bifidobacterium* and *Lactobacillus* (Aoun et al., 2020), with higher doses promoting *Lactobacillus* selectively (Wiese et al., 2019). Prebiotics alter gut bacteria and metabolism to benefit the host and reduced intake decreases their growth. SCFA from gut bacteria uplift intestinal permeability as colon cells get energy and affect L-cells to increase peptide release (Delgado & Tamashiro, 2018).

Foods that Promote a Healthy Gut Microbiome

Fermented foods: foods like yoghurt, kimchi, sauerkraut, kefir, and tempeh are rich in beneficial bacteria such as *lactobacilli*, which support microbiome function and reduce harmful organisms (Christie & Andrea, 2021).

Dandelion greens: These fiber-rich greens boost the immune system by increasing beneficial microbes, particularly *Bifidobacteria* this enhance your immune system (Mahboubi & Mahboubi, 2020)

Garlic: known for its antioxidants and anti-inflammatory properties. It promotes the growth of healthy *Bifidobacteria*, helping maintain a strong immune system (Li et al., 2022).

Onions and Leeks: Both are nutrient-dense and rich in inulin, which nourishes gut bacteria and aids digestion, while also providing antioxidant benefits (Vinke et al., 2017; Hedges & Lister, 2007).

Chicory root: Chicory root is a popular decaffeinated coffee replacement. High in inulin fiber, chicory root supports healthy gut flora and may aid in glucose regulation (El-Kholy et al., 2020).

Cereals: Barley is rich in beta-glucan fiber, which supports gut microbes. Wheat bran increases beneficial *Bifidobacteria* and helps alleviate digestive issues like gas and cramps (Jefferson & Adolphus, 2019). Oats contain beta-glucan fiber and resistant starch, which support gut health, lower LDL cholesterol, help manage blood sugar, reduce obesity, and decrease cancer risk (Henrion et al., 2019).

Cocoa beans: are the seeds of the Theobroma cacao tree and are rich in polyphenols. They have antioxidant and anti-inflammatory properties, promote healthy gut bacteria, and inhibit harmful bacteria (Sorrenti et al., 2020).

Flaxseeds: are highly nutritious and function as a prebiotic, promoting healthy gut bacteria and regular bowel movements while aiding in blood sugar regulation (Khan et al., 2023).

Yacon root: are similar to sweet potatoes, is rich in fiber and inulin, benefiting digestive health, mineral absorption, and immune support, while also helping to regulate blood sugar levels (Singla & Chakkaravarthi, 2017).

Green Tea: contains higher amounts of polyphenols, which fight against "harmful" microbes and in the alleviation of symptoms of inflammatory bowel disease (IBD) and peptic ulcers. Polyphenols can also encourage the growth of beneficial gut flora by acting as prebiotic (Truong & Jeong, 2022).

Conclusion

In conclusion, overall health and well-being is depicted by gut microbiota, which is shaped by various factors, including the mode of childbirth, genetic predisposition, lifestyle choices, and medication use and environment exposures. A healthy gut microbiome not only promotes wellness but also helps prevent health issues such as obesity by serving as a protective barrier. Incorporating dietary changes, along with probiotics and prebiotics supports the maintenance of gut health. Probiotics and prebiotics are potent tools for modulating gut flora, promoting beneficial microbial populations, and counteracting Dysbiosis, which is often associated with weight gain and obesity. A varied and diverse diet, including fermented foods, high-fiber foods and specific vegetables, can positively impact gut microbiota composition. Different diet patterns, such as Western diet, high protein, vegetable, Mediterranean, high fiber, high fat diets uniquely influence the gut bacteria. By understanding the complex interactions between gut microbiota and weight regulation, we can develop therapeutic strategies that optimize microbiota composition through personalized diets and targeted supplementation.

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