

LINKING GUT MICROBIOTA AND IRRITABLE BOWEL SYNDROME (IBS): A REVIEW

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Submitted on 14 April 2025, accepted on 25 August 2025

Abstract: Irritable bowel syndrome (IBS) is a chronic gastrointestinal disorder with an increasing global prevalence. The International Classification of Diseases (ICD) system typically categorizes IBS into four subtypes based on symptomatology. The objective of this review is to provide a concise synthesis of the most current information regarding IBS, encompassing widely accepted diagnostic criteria, etiology, epidemiological data and the significance of gut microbiota (GM) in pathogenesis of this disorder. Additionally, it will explore future perspectives. Recent studies have demonstrated that the GM in healthy individuals primarily consists of four main bacterial phyla: *Firmicutes* spp., *Bacteroidetes* spp., *Actinobacteria* spp., and *Proteobacteria* spp. Dysbiosis or an imbalance in these bacteria may be a contributing factor to the IBS development. It is imperative to acknowledge the multifaceted role of the GM in several essential biological processes, including: immunomodulation, intestinal barrier integrity, gut microbiota-gut-brain axis (GBA) or nutrient absorption. The composition of GM is subject to variation depending on the IBS subtype. Many therapeutic strategies have been devised for the treatment of patients with IBS, comprising antibiotics, probiotics, prebiotics, synbiotics and fecal microbiota transplantation (FMT). Although FMT has shown promise, clinical trials outcomes remain still inconsistent. Dietary interventions and psychological support are also vital components of IBS management.

Despite the advances in understanding the GM-IBS relationship, there is still a lack of knowledge regarding specific microbial markers for each IBS subtype. Consequently, a definitive microbiota pattern has yet to be delineated. However, emerging evidence underscores the microbiome's role in IBS pathophysiology.

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Keywords: gut microbiota/microbiome, IBS, irritable bowel syndrome

1. Introduction

Irritable bowel syndrome is one of the most common functional, gastrointestinal disorder (FGID) characterized by occurrence of following symptoms: bloating, discomfort, abdominal pain, abnormal stool characteristics, changes in bowel habits (constipation or diarrhea). Also symptoms not associated with di-

gestive system were reported including: chronic pelvic pain, temporomandibular joint disorder, fibromyalgia and chronic fatigue syndrome (Cheng et al. 2024; Aggelatopoulou and Triantos 2024; Li et al. 2024). As it was mentioned above, IBS is classified as FGID what means that symptoms (particularly gastrointestinal) cannot be described in the context of structural or metabolic abnormalities (Shaikh et al. 2023). This disorder might

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Cite as:

Linking gut microbiota and irritable bowel syndrome (IBS): a review. Karasek M. et al., ADV MICROBIOL-NY, 2025, 64, 3, 147-159, <https://doi.org/10.2478/am-2025-0012>

be divided into four subtypes: constipation-predominant (IBS-C), diarrhea-predominant (IBS-D), mixed (IBS-M), and unsubtyped (IBS-U) according to the Rome IV 2016 (Palsson et al. 2016). Also Bristol Stool Form Scale (BSFS) plays a role in the determination of IBS subtype. This scale assumes characterization of stool consistency from hard to soft based on the scale 1-7 (Shaikh et al. 2023). IBS affects approximately 10-20% population and negatively impacts on the patient's life quality including psychological issues (Pittayanon et al. 2019). It was reported that among patients with this disorder occurred such mental health problems as for example anxiety, depression, suicidal thoughts or work productivity impairment. Moreover, patient with IBS annually often spend much money on medical care (Aggeletopoulou and Triantos 2024; Chong et al. 2019). Currently, there are no diagnostics criteria and IBS is diagnosed based on mainly patient's symptoms, medical history and by using imaging methods routinely used in gastroenterological practice like endoscopy (Cheng et al. 2024). There are also no biomarkers or specific laboratory tests which could be helpful in the diagnosis and management of this gastrointestinal disease (Shrestha et al. 2022). It highlights that IBS is a challenge in the clinical practice. The pathophysiology of IBS is intricate and not yet fully elucidated. It is widely accepted that this phenomenon arises from disruptions in the complex interactions between the gastrointestinal system and the central nervous system. These disturbances have been hypothesised to result in visceral hypersensitivity, intestinal motility disorders and abnormal signal processing in the central nervous system. The predominant pathophysiological mechanisms of IBS are (a) microbiological or functional disorders of the brain-gut axis, resulting from bacterial overgrowth or disrupted communication, which affects the functioning of the gastrointestinal tract; and (b) altered gastrointestinal motility disorders (abnormal contractions leading to diarrhoea, constipation or alternating periods of both); (c) visceral hypersensitivity associated with pain and discomfort, even in the absence of peristaltic movement; (d) disorders in the intestinal immune system (intestinal inflammation), including excessive immune stimulation or hypersensitivity to food allergens; (e) intestinal dysbiosis, i.e. an imbalance of intestinal microorganisms, both qualitative and quantitative; (f) psychological factors, including prolonged or acute stress, other psychological disorders (low mood, anxiety symptoms, depression, grief), as well as adverse childhood experiences

(ACE), which may exacerbate the symptoms of irritable bowel syndrome (IBS); (g) genetic predisposition; (h) previous intestinal infections resulting in permanent alterations in the functioning of the gastrointestinal tract (post-infectious reactivity); (i) a diet that is particularly rich in Fermentable Oligosaccharides, Disaccharides, Monosaccharides, And Polyols (FODMAPs) can trigger symptoms in individuals diagnosed with IBS (Cheng et al. 2024; Li et al. 2024; Almonajjed et al. 2025).

A significant number of authors have considered also the psychosomatic basis of IBS. The manifest symptoms of the digestive system are not necessarily directly related to the pathology of this system itself or the physiological changes that occur in the intestines. It is frequently cited that adverse childhood experiences (ACEs) resulting from severe traumatic events during childhood or adolescence, experiences of extreme poverty, illness in close family members, or war are often mentioned in this context. It is acknowledged that early childhood trauma has the capacity to influence the development of IBS through two primary neurobiological mechanisms. Firstly, there is the dysregulation of the hypothalamic-pituitary-adrenal axis, which can lead to dysregulation of intestinal motility and intestinal dysbiosis. Secondly, there is the disturbance of the brain-gut axis, which can result in, for example, misprocessing of information from the intestines, hypersensitivity and a low pain threshold. The combination of all functional gastrointestinal symptoms of IBS with stress (via neural, hormonal and immune signalling) has been shown to cause further exacerbation of gastrointestinal symptoms, resulting in positive feedback (Almonajjed et al. 2025; Chong et al. 2019; Staudacher et al. 2023).

The purpose of this concise review is to explore the underlying causes of discomfort and the associated symptoms that contribute to the development and perpetuation of this multifaceted disorder. The primary objective of the present review is to emphasise the significance of the GM in the etiopathogenesis and progression of IBS.

2. Gut microbiota

The intestinal microbiota/microbiome comprises bacteria, viruses, protozoa and fungi, all of which play a vital role in maintaining the health of the host. These microorganisms play a pivotal role in a multitude of functions that are indispensable for the proper

functioning of the human organism. Such functions include drug and nutrient metabolism, protection against pathogens and modulation of the immune response (Aggeletopoulou and Triantos 2024; Shaikh et al. 2023). The composition of the intestinal microbiota is influenced by several environmental factors, including age, sex, ethnicity and diet or geographical localisation (Shaikh et al. 2023). The preponderance of bacteria in the intestinal ecosystem has led to the nomenclature of this complex as GM (Cheng et al. 2024).The development of GM has been observed since early childhood (Almonajjed et al. 2025). In the context of healthy individuals, the predominant phyla include *Bacteroides* spp., *Clostridium* spp., *Bifidobacterium* spp. and *Lactobacillus* spp. (Cheng et al. 2024; Almonajjed et al. 2025; Shaikh et al. 2023; Menees and Chey 2018). It is widely accepted that bacteria present in the intestines can be categorised into two distinct groups: namely, beneficial bacteria and pathogenic bacteria. The former are primarily represented by the phyla mentioned above: *Bacteroides* spp., *Clostridium* spp., *Bifidobacterium* spp. and *Lactobacillus* spp. It is now evident that these bacteria are involved in facilitating a multitude of beneficial processes within the human organism, including the synthesis of vitamins

(e.g. K₂, B₁, B₂, B₆, B₇, B₉, and B₁₂) and the production of (SCFAs, e.g. acetate, butyrate, and propionate), amino acids, carbohydrates, and lipids, the absorption of important ions (e.g. magnesium, iron, and zinc), the biosynthesis of cholesterol from bile acids (BAs), and the protection against different pathogens by the production of antimicrobial substances (e.g. bacteriocins and lactic acid) (**Table 1**). The second group of GM comprises opportunistic bacteria with pathogenic potential, including enteric bacteria such as *Salmonella* spp. and *Escherichia coli*. These bacteria are responsible for the production of harmful substances that can lead to various pathological conditions. Furthermore, opportunistic bacteria, including *Enterococcus* spp. and *Enterobacteriales*, have been identified as significant contributors to diseases, particularly in individuals with compromised immune systems (Cheng et al. 2024). The composition of the gut microbiome can be studied using a variety of molecular methods, including terminal restriction fragment length polymorphism, 16S ribosomal RNA (rRNA) gene sequencing, quantitative polymerase chain reaction (qPCR), fluorescent *in-situ* hybridization, bacterial culture or microarrays (Pitayanon et al. 2019).

Table 1: Examples of gut microbiota phyla and taxa, along with an analysis of their role in the functioning of the human organism based on (Almonajjed et al. 2025; Mamieva et al. 2022)

Phylum	Taxa	Role
Firmicutes	<i>Enterococcus</i> , <i>Ruminococcus</i> , <i>Clostridium</i> , <i>Lactobacillus</i> , <i>Faecalibacterium</i> , <i>Roseburia</i> , <i>Eubacterium</i>	metabolism of amino acids, carbohydrates and lipids, the transformation of BAs and the biosynthesis of cholesterol, the synthesis of vitamins (K ₂ , B ₁ , B ₂ , B ₆ , B ₇ , B ₉ and B ₁₂) support the integrity of the intestinal epithelial barrier and protection against enteric infections
Bacteroidetes	<i>Bacteroides</i> , <i>Prevotella</i>	immunomodulation, appetite regulation
Actinobacteria	<i>Bifidobacterium</i> , <i>Corynebacterium</i>	vitamin synthesis, BAs metabolism, protection against infections
Proteobacteria	<i>Shigella</i> , <i>Escherichia</i> , <i>Desulfovibrio</i>	amino-acids metabolism

3. Epidemiology of IBS

The global prevalence of IBS varies depending on the diagnostic criteria used and the geographical location. Based on Rome IV criteria, the global prevalence of IBS is estimated at 3.8%. The highest prevalence is

found in South America (21%), while the lowest in Southeast Asia (7%) (Oka et al. 2020). IBS is more prevalent among women than men, with an approximate female-to-male ratio of about 2:1 in Western countries (Sperber et al. 2021; Lovell and Ford 2012). Women more frequently report IBS-C, while men more often

report IBS-D (Lovell and Ford 2012). Onset typically occurs before age 50, often in late adolescence or early adulthood (Canavan et al. 2014). IBS is more frequently reported in Western countries, although underdiagnosis in low- and middle-income countries due to lack of access to healthcare and cultural differences in symptom reporting may mean that the true prevalence is underestimated (Oka et al. 2020; Sperber et al. 2021). A higher prevalence is often observed in urban areas and among individuals with a higher level of education and a higher socioeconomic status, potentially due to increased access to healthcare and health-seeking behaviour (Hungin et al. 2005).

4. The role of gut microbiota in the pathogenesis of irritable bowel syndrome

The role of the GM in the development of IBS is a subject that has attracted considerable interest from the scientific community. This group of microorganisms plays a number of pivotal roles in a variety of processes, including the production of different metabolites from absorbed nutrients in the intestines, the regulation of GBA, mucosal immune regulation, intestinal barrier dysfunction, gastrointestinal motility and visceral sensitivity (Almonajjed et al. 2025; Mamieva et al. 2022; Cheng et al. 2024).

4.1. Gut microbiota metabolic products

The development of IBS is significantly impacted by GM, which produces various metabolic factors, including SCFAs, neurotransmitters (e.g. serotonin), lipopolysaccharides, peptidoglycans, BAs and signalling molecules. These products are derived from nutrients absorbed in the intestines and subsequently metabolised by GM through a series of metabolic processes. It is evident that all these factors collectively influence the manifestation of IBS symptoms (Cheng et al. 2024).

Bile acids are synthesised in the human intestine by a variety of bacterial phyla, including: *Bacteroides*, *Clostridium*, *Lactobacillus*, *Listeria*, and *Bifidobacterium*. It has been demonstrated that alterations in the concentration of BAs have been demonstrated to induce cytotoxic effects, encompassing apoptosis, necrosis and DNA damage. These alterations are considered a primary contributing factor to the development of IBS. An imbalance in the synthesis of BAs has been particularly observed among patients with IBS-D, who also exhibit decreased levels of bacteria belonging to

the Ruminococcaceae family (Aggeletopoulou and Triantos 2024; Shrestha et al. 2022).

SCFAs, including butyrate and propionic acids, are a by-product of the anaerobic metabolism of carbohydrates and play a pivotal role in maintaining intestinal barrier integrity and regulating immune functions (Cheng et al. 2024; Aggeletopoulou and Triantos 2024). In addition to their role in metabolism, SCFAs have also demonstrated the capacity to exhibit anti-inflammatory activity. Reduced levels of SCFAs have been observed primarily among patients diagnosed with IBS-C (Cheng et al. 2024). SCFAs play a crucial role in the synthesis of serotonin, a neurotransmitter of significant importance within the central nervous system (CNS). Serotonin is synthesised from tryptophan by enterochromaffin (EC) cells or directly by bacteria. This neurotransmitter is responsible for gut peristalsis, regulation of secretion and vasodilator function (Aggeletopoulou and Triantos 2024; Shaikh et al. 2023; Mamieva et al. 2022). Increased serotonin synthesis has been linked to diarrhea (IBS-D), while reduced serotonin levels have been associated with IBS-C (Shaikh et al. 2023; Mamieva et al. 2022). Additionally, SCFAs have been identified as modulators of glucagon-like peptide 1 (GLP-1) secretion by intestinal L-cells. The bacteria representing *Clostridium* spp., *Bacteroides* spp. and *Ruminococcus* spp. are the main contributors to this process (Mamieva et al. 2022). The primary function of GLP-1 is to reduce motility in the antrum, duodenum and jejunum (Mamieva et al. 2022). Levels of this factor are reduced in patients diagnosed with IBS-C (Li et al. 2017). Furthermore, SCFAs have been identified as promising biomarkers for IBS (Cheng et al. 2024).

It is evident that components of the bacterial cell wall, such as lipopolysaccharides (LPS) and peptidoglycans (PGs), play a pivotal role in the activation of the immune system through the recognition process by Toll-like receptors (TLRs). Thereafter, immune cells secrete various cytokines and mediators, which are instrumental in the process of immune response. Of particular significance is the secretion of histamine by mast cells, a process that is implicated in the occurrence of gut permeability, mucosal inflammation and visceral hypersensitivity, which are characteristic of IBS symptoms (Cheng et al. 2024; Aggeletopoulou and Triantos 2024).

In conclusion, it is evident that GM metabolic products play a pivotal role in the regulation of gastrointestinal functions, immunomodulation, and the synthesis

of factors necessary for the normal functioning of the human organism. Conversely, there is also evidence to suggest that metabolic products have also been associated with the symptoms and progression of IBS.

4.2. Mucosal immune regulation

The immune response in patients diagnosed with IBS has been shown to be dysregulated. This has been linked to the migration of immune cells, primarily mast cells, to the intestinal mucosa, leading to the onset of inflammation (Aggeletopoulou and Triantos 2024; Mamieva et al. 2022). In response to the recognition of bacterial antigens by TLRs, mast cells secrete a range of immune response mediators, including histamine, tryptamine, prostaglandins, serotonin and proteases. The mediators in question have been identified as playing a crucial role in immunotolerance (Cheng et al. 2024; Aggeletopoulou and Triantos 2024). The aforementioned mediators have been linked to the occurrence of IBS symptoms, visceral hypersensitivity, altered pain threshold and intestinal barrier dysfunction (Aggeletopoulou and Triantos 2024; Almonajjed et al. 2025; Mamieva et al. 2022). Furthermore, an additional finding of significance is the observation that tryptase release is a causative factor in the reduction of expression of tight junction proteins, thereby increasing gut permeability (Almonajjed et al. 2025; Mamieva et al. 2022). A plethora of studies have identified elevated levels of various immune mediators, including IL-6, IL-8, IL-12, IL-1 β and tumour necrosis factor- α (TNF- α), in patients with IBS. Conversely, a paucity of research has been observed with regard to IL-10 levels, which have been shown to be reduced in such cases (Aggeletopoulou and Triantos 2024; Mamieva et al. 2022). The immune response is influenced by the production of metabolites by several phyla. Bacteria belonging to the phylum *Firmicutes* are responsible for the production of butyrate, which is involved in the differentiation of regulatory T-cells (Treg.) (Mamieva et al. 2022). *Lactobacillus* spp. transform tryptophan into indole-3-aldehyde, which leads to the activation of the aryl hydrocarbon receptor (AHR). The AHR is involved in the regulation of the number of intraepithelial lymphocytes and IL-22 production (Almonajjed et al. 2025; Mamieva et al. 2022). Furthermore, *Lactobacillus rhamnosus*, *Lactobacillus casei* and *Bifidobacterium breve* have been observed to induce IL-4 and IL-10 production, while *L. reuteri* and *L. plantarum* have been shown to downregulate the expression of TNF- α

(Mamieva et al. 2022). Butyrate-producing *Faecalibacterium prausnitzii* is a bacterial species that has been shown to be responsible for anti-inflammatory activity through inhibition of IL-8 synthesis, activation of regulatory T-cells (Treg) and increased secretion of IL-10 (Almonajjed et al. 2025). In patients diagnosed with post-infectious IBS (PI-IBS), an increased abundance of *Bacteroidetes* and a concurrent decrease in *Clostridiales* have been observed. These changes have been shown to correlate with elevated levels of cytokines (IL-1 β and IL-6), which are involved in inflammatory processes (Aggeletopoulou and Triantos 2024).

The scientific literature indicates that GM play a crucial role in regulating immune responses, and that they are involved in the pathophysiology of IBS, with a consequent effect on the severity and symptoms of the condition.

4.3. Intestinal barrier dysfunction

The intestinal barrier plays a pivotal role in preserving gut homeostasis, a process that involves the prevention of antigen migration to the mucosa and the subsequent development of mucosal inflammation (Mamieva et al. 2022). The intestinal barrier dysfunction is a multifaceted condition, with involvement of both metabolic and immune pathways (Mamieva et al. 2022). A salient feature of intestinal barrier dysfunction is its high prevalence among patients diagnosed with IBS-D (Almonajjed et al. 2025). The underlying causes of this increased gut permeability are multifaceted, including, but not limited to, reduced expression of tight junction proteins, such as occludin, claudins, and zonula occludens-1, in the duodenum, colon, and jejunum (Cheng et al. 2024; Mamieva et al. 2022; D'Antongiovanni et al. 2020). The role of GM in maintaining intestinal integrity is significant, with bacteria from the phylum *Firmicutes* (*Eubacterium* spp., *Clostridium* spp., *Ruminococcus* spp. and *Faecalibacterium* spp.) producing SCFAs. Recent studies have demonstrated the pivotal function of these SCFAs in modulating the expression of claudins (3 and 4) and occludins (Almonajjed et al. 2025; Mamieva et al. 2022). The production of E-cadherin and zonula occludens-1 is stimulated by genera such as *Clostridium* spp., *Enterococcus* spp., *Streptococcus* spp. and *Lactobacillus* spp., which are involved in the production of polyamines (Almonajjed et al. 2025; Mamieva et al. 2022). Tight junction protein ZO-2 plays a crucial role in maintaining the intestinal barrier function, with its expression being

stimulated by bacteria *E. coli* (Cheng et al. 2024). Probiotic bacteria, typified by *Lactobacillus* spp. and *Bifidobacterium* spp., have been demonstrated to exert a beneficial influence on the intestinal barrier function of patients with IBS through the inhibition of increased permeability and the regulation of secretion of both pro- and anti-inflammatory mediators (Cheng et al. 2024; Almonajjed et al. 2025; Mamieva et al. 2022). The results of a study by Edogawa et al. (Edogawa et al. 2020) demonstrated the role of fecal proteases in the increased intestinal barrier permeability and disruption of tight junction proteins (Aggeletopoulou and Triantos 2024; Edogawa et al. 2020). Increased proteolytic activity was especially noticeable among patients with PI-IBS and was to affect the severity of symptoms (Aggeletopoulou and Triantos 2024; Edogawa et al. 2020). Furthermore, GM has been demonstrated to play a pivotal role in mucus production, which in turn serves as a protective barrier between the epithelial cells and the intestinal lumen (Aggeletopoulou and Triantos 2024). The composition of the mucus layer is primarily influenced by bacteria such as *Ruminococcus* spp., *Bacteroides thetaiotaomicron* and *F. prausnitzii* (Aggeletopoulou and Triantos 2024; Almonajjed et al. 2025).

4.4. Gut microbiota-brain axis

The gut-brain axis is defined as a system of bidirectional communication between the gastrointestinal tract and the nervous system (both the central nervous system and the autonomic nervous system) involving neuronal, endocrine and immune pathways (Cheng et al. 2024; Shrestha et al. 2022; Baj et al. 2019). This interaction has been demonstrated to regulate gut motility and sensitivity, also in addition to modulating emotional and pain responses (Aggeletopoulou and Triantos 2024). It is hypothesised that this connection is involved in IBS development. The concept of a GBA has been proposed, suggesting a potential role for GM in this process (Cheng et al. 2024). The GM has been implicated in the production of neurotransmitters (e.g. serotonin), modulators, and metabolites (e.g. short-chain fatty acids, tryptophan), as well as in maintaining the integrity of the intestinal barrier (Aggeletopoulou and Triantos 2024; Shrestha et al. 2022). The influence of the gut microbiome on the functioning of patients diagnosed with IBS is a subject of much debate, with studies suggesting both positive and negative influences (Aggeletopoulou and Triantos 2024).

It has been observed that pathogenic bacteria, such as *Pseudomonas aeruginosa* and *Campylobacter jejuni*, have been shown to proliferate in an environment stimulated by stress-related neurotransmitters. These bacteria have been implicated in the enhancement of gut permeability, the onset of visceral pain, and, in the case of *P. aeruginosa*, the promotion of inflammatory activity (Aggeletopoulou and Triantos 2024). Cytokines, defined as proteins that regulate the immune system, have been implicated in inflammatory processes. The principal cytokines involved are IL-6, IL-8 and TNF- α , which have also been associated with stress, anxiety and depression in IBS (Almonajjed et al. 2025). Recent studies have demonstrated that neuroinflammation can be triggered by SCFAs produced by bacteria. These SCFAs have been observed to stimulate the recruitment of immune cells within the affected area (Shrestha et al. 2022). Conversely, beneficial microorganisms, exemplified by bacteria such as *Bifidobacterium* spp., have been observed to produce neurotransmitters including gamma-aminobutyric acid (GABA) and serotonin. The efficacy of these compounds in enhancing serotonin receptor expression and mitigating the deleterious effects of diverse stimuli on the brain has been demonstrated (Aggeletopoulou and Triantos 2024). Consequently, they have been shown to modulate patient mood and stress responses in a positive manner, thereby enhancing overall well-being

indicating considerable corpus of evidence has been amassed which indicates the involvement of GM in the regulation of the hypothalamic-pituitary-adrenal (HPA) axis. The process is primarily driven by pro-inflammatory cytokines (IL-6 and IL-8), which are produced by *Aspergillus fumigatus*, *Candida albicans*, and *Saccharomyces cerevisiae* fungi in the intestinal mucosa (Shrestha et al. 2022; Chong et al. 2019). The ultimate outcome of this axis is the secretion of cortisol from the adrenal cortex. Dysregulation of this axis is hypothesised to be the underlying cause of the psychological disorders experienced by patients with IBS, including anxiety, stress and depression. These disorders have been shown to affect visceral hypersensitivity, intestinal motility and permeability, GM composition and immune response (Mamieva et al. 2022; Chong et al. 2019). Among these patients, an increased abundance of *E. coli*, *Pseudomonas* spp., *Enterobacteriaceae* family, *Streptococcus* spp., *Prevotella* spp., and *Clostridium* spp. has been observed, while levels of *Lactobacillus* spp. have been shown to be decreased (Shrestha et al. 2022).

5. Changes in the gut microbiota composition in dependence on subtype of IBS

Recent research (Cheng et al. 2024; Chong et al. 2019; Surdea-Blaga et al. 2024) has focused on alter-

ations in the qualitative and quantitative composition of the gastrointestinal microbiota in patients diagnosed with IBS, categorised by age and other health parameters (Table 2).

Table 2: Differences in gut microbiota qualitative-quantitative composition in depending on subtype of irritable bowel syndrome.

Subtype	Changes in gut microbiota		Ref.
	increase	decrease	
IBS-D	<i>Enterobacteriaceae, Proteobacteria, Firmicutes, Clostridiales, Bacteroides, Lactobacillus, Prevotella, Escherichia coli, Pseudomonas aeruginosa, Dorea</i>	<i>Actinobacteria, Bacteroidetes, Ruminococcaceae, Methanobacteriaceae, Parasuterella, Lactobacillus, Bifidobacterium, Prevotella, Enterococcus, Faecalibacterium, Lachnospira, Turicibacter, Weisella, Oxolobacter, Oceanobacillus, Collinsella aerofaciens</i>	Cheng et al. 2024; Chong et al. 2019; Surdea-Blaga et al. 2024
IBS-C	<i>Bacteroides, Clostridiales, Christensenellaceae, Veilonella, Akkermansia, Methanobrevibacter, Pseudomonas aeruginosa, Methanobrevibacter smithii</i>	<i>Bacteroides, Methanobrevibacter, Bifidobacterium catenulatum, Prevotella</i>	Cheng et al. 2024; Chong et al. 2019; Surdea-Blaga et al. 2024
IBS-M	-	<i>Faecalibacterium prausnitzii</i>	Cheng et al. 2024
IBS-U	<i>Pseudomonas aeruginosa</i>	-	

6. Therapeutic approach in irritable bowel syndrome

A considerable number of therapeutic strategies have been developed for the purpose of modulating the composition of the GM in patients diagnosed with IBS. These strategies encompass dietary modifications, the supplementation of antibiotics, probiotics, synbiotics, prebiotics, postbiotics, and FMT (Cheng et al. 2024; Aggeletopoulou and Triantos 2024).

6.1. Diet

In the context of treating patients suffering from IBS, diet plays a pivotal role, with low FODMAPs being of particular significance. Evidence suggests that this dietary is efficacious in reducing symptoms associated with IBS, including bloating, visceral pain and general discomfort (Cheng et al. 2024; Almonajjed et al. 2025; Chong et al. 2019). The ingestion of plant-based proteins has been associated with an increased levels of beneficial bacteria (e.g. *Bifidobacterium* spp., *Lactobacillus* spp.) and a decreased levels of pathogenic

bacteria (e.g. *Bacteroides fragilis* and *Clostridium perfringens*) (Shaikh et al. 2023). The low FODMAP diet has also been observed to reduce inflammatory activity and increase gut permeability (Aggeletopoulou and Triantos 2024). However, it is important to note that this dietary approach is associated with certain disadvantages, including nutritional deficiencies, reduced fibre intake, constipation, and an imbalance in GM composition, characterised by decreased levels of beneficial bacteria (Cheng et al. 2024; Almonajjed et al. 2025). Additionally, the efficacy of this therapeutic approach may be subject to variation depending on the IBS subtype (Almonajjed et al. 2025).

6.2. Antibiotics

Antibiotics have been posited as a potential novel therapeutic approach in the management of IBS. In clinical practice, a range of antibiotic medications have been employed, including neomycin, doxycycline, amoxicillin/clavulanate, norfloxacin, and rifaximin (Cheng et al. 2024; Shaikh et al. 2023). Notably, the lat-

ter was endorsed by the American Journal of Gastroenterology for the management of IBS (Shaikh et al. 2023). The benefits of rifaximin include a limited spectrum of side effects, low levels of resistance and toxicity, and ease of administration (by mouth) (Shaikh et al. 2023; Chong et al. 2019). The effectiveness of rifaximin was emphasized in two clinical trials (TARGET 1 and TARGET 2), where improvements in symptoms were evident among patients with IBS-D in comparison to the control group (Shaikh et al. 2023). Antibiotics, as a form of targeted therapy, have been shown to reduce levels of pathogenic bacteria, such as *E. coli* and *Enterobacteriaceae* (Aggeletopoulou and Triantos 2024). The beneficial effect of antibiotics in IBS has been observed in the reduction of symptoms, including bloating or general discomfort (particularly in IBS-D), and alterations in immune and inflammatory responses (Aggeletopoulou and Triantos et al. 2024; Shaikh et al. 2023). It is imperative to emphasise that patients diagnosed with IBS should adhere to antibiotic usage guidelines, as misuse of these medications can lead to an escalation in bacterial resistance, the emergence of adverse effects, resistance to the antibiotic treatment, and a disruption in the intestinal microbiota (i.e. dysbiosis) (Cheng et al. 2024).

6.3. Prebiotics, probiotics, synbiotics and postbiotics

The qualitative and quantitative composition of the GM can be modified to a considerable extent through simple means (Table 3). Such modifications can be achieved by adjusting dietary habits to incorporate fibre-rich foods, as well as by introducing probiotic bacterial supplements that have been demonstrated to possess beneficial properties. The efficacy of a probiotically enriched microbiome can be augmented by paraprobiotic preparations (i.e. non-viable, inactivated bacteria or their cellular components) and/or postbiotic preparations (i.e., products of bacterial metabolism or equivalent synthetic products that beneficially modulate the immune response of the macroorganism and reduce inflammation) (Martyniak et al. 2021). The aforementioned approaches are used to: (a) the binding of immune function, (b) the alleviation of symptoms of irritable bowel disease, (c) the reduction of the severity of allergies, (c) the prevention and treatment of tooth decay, and (d) the prevention and treatment of metabolic syndrome (Luzzi et al. 2024).

Table 3: Prebiotics, probiotics, synbiotics and postbiotics used in alleviating symptoms of irritable bowel syndrome

Biotics in prophylaxis or therapeutic approach	Potential use for the prevention and treatment	Therapeutic activity	Ref.
Probiotics	Beneficial bacteria strains that can be administered orally as a dietary supplement	The reduction on gut inflammation, increase the level of beneficial bacteria (<i>Lactobacillus</i> spp., <i>Bifidobacterium</i> spp.), inhibition of growth of pathogenic bacteria, modulation of both anti- and pro-inflammatory cytokines, participation in production of SCFAs, production of neurotransmitters, improve symptoms in IBS (e.g. abdominal pain, bloating), tighten gut barrier, regulation of GBA, improve gut barrier integrity and mucus production, reduction of intestinal permeability, improve patient’s quality of life and mood, influence on the both innate and adaptive immunity, with interaction occurring with epithelial cells, dendritic cells, macrophages and lymphocytes through pattern-recognition receptors, helping regulate Tcell balance (especially boosting Treg. to reduce inflammation), prevention antibiotic-associated diarrhea, necrotizing enterocolitis, pouchitis, and traveler’s diarrhea, <i>in vitro</i> and animal studies indicate improved burn wound healing with <i>Saccharomyces cerevisiae</i> , and prevention or reduction of eczema through mechanisms involving the GBA	Cheng et al. 2024; Aggeletopoulou and Triantos 2024; Almonajjed et al. 2025; Shaikh et al. 2023; Martyniak et al. 2021; Luzzi et al. 2024; Qiao et al. 2025; Maftai et al. 2023; Campaniello et al. 2023; Rijkers et al. 2011; Ranjha et al. 2021; Fuochi and Furneri 2023

Prebiotics	• Dietary fibers that are non-digestible food components by human enzymes and not absorbed by the human small intestine. They reach the colon where they are fermented by bacteria present in the GM • Present naturally in multitude of plant foods, including artichokes, asparagus, chicory, garlic, onions, wheat, and bananas • It can be synthesised and incorporated into food products	Promotion of growth of beneficial bacteria, improve symptoms in irritable bowel syndrome, production of SCFAs (including butyrate, propionate and acetate), regulation of gut motility, improve intestinal barrier function, reduction of inflammatory processes, anti-oxidative activity, regulation of cholesterol and lipids synthesis	Aggeletopoulou and Triantos 2024; Almonajjed et al. 2025; Shaikh et al. 2023; Chong et al. 2019; Martyniak et al. 2021; Luzzi et al. 2024
Synbiotics	• Products that contain both prebiotics and probiotics • It is possible to formulate such products in two different ways: the first approach, known as the complementary approach, the prebiotic and probiotic substances work independently; in the second approach, known as the synergistic approach, the prebiotic and probiotic substances work together	Improve probiotics survival in gastrointestinal tract, reduction of symptoms in IBS (bloating, abdominal pain), increase a bowel movement frequency, reduction of levels of pro-inflammatory cytokine (IL-8, TNF- α) and increase of levels of anti-inflammatory cytokines (IL-10), improve intestinal barrier integrity and gut motility	Almonajjed et al. 2025; Shaikh et al. 2023; Chong et al. 2019; Martyniak et al. 2021; Luzzi et al. 2024
Postbiotics	• Classified as either (a) products resulting from bacterial metabolism, or (b) synthetic products that possess the capability to modulate inflammation and the immune response	It is assumed that improve symptoms in IBS (particularly in IBS-D) and reduce inflammatory activity	Almonajjed et al. 2025; Martyniak et al. 2021

6.4. Fecal microbiota transplantation (FMT)

Another therapeutic approach in the treatment of IBS is FMT. This strategy involves the transfer of a stool solution from healthy individuals to patients with IBS, with the objective of restoring a healthy GM composition, improving its diversity, increasing the level of beneficial bacteria and decreasing the level of pathogenic species particularly associated with IBS (Almo-

najjed et al. 2025). FMT leads to strengthening of the intestinal barrier, reduction of inflammatory processes, modification of the immunological response and, potentially, improvement of the GBA (Almonajjed et al. 2025). The application of FMT in the treatment of patients infected with *Clostridioides difficile* has been documented (Cheng et al. 2024; Shaikh et al. 2023). FMT donors might be both healthy relatives or anonymous. In case of anonymous donors there is an oppor-

tunity to select donors with a high diversity in the composition of GM and obtained stool might be stored in the freezers by a long time and then used for multiple patients (Cammarota et al. 2019; Halkjær et al. 2023). There are several methods which can be used in FMT including endoscopic procedures or using gastro-duodenal or rectal tube. Also capsules delivery led to release the stool in the small intestines (Halkjær et al. 2023). The results obtained from various randomised clinical trials (RCTs) have been found to be inconsistent. Studies carried out by El Salhy et al. (El-Salhy et al. 2019), Johnsen et al. (Johnsen et al. 2018) and Holvoet et al. (Holvoet et al. 2021) have demonstrated a favourable clinical response following FMT treatment, characterized by an enhancement in symptoms related to IBS, in comparison to the control group that received a placebo. Conversely, the results of randomised clinical trials conducted by Halkjær et al. (Halkjær et al. 2018) demonstrated that the control group (placebo) exhibited a superior clinical response in comparison to patients who had undergone FMT. The observed variations in outcomes among studies may be attributable to several factors, including individual patient characteristics, delivery method, or donor selection (Almonajjed et al. 2025). At present, FMT is not recommended as a first-line treatment for IBS, and further research is required to ascertain the beneficial effect of FMT on the therapeutic success of patients with IBS (Cheng et al. 2024; Chong et al. 2019).

6.5 Mind-body therapies

The experiences of numerous clinicians have underscored the necessity to monitor the mental health of patients diagnosed with IBS. In the context of diagnosis and treatment, the incorporation of patient surveys has been demonstrated to facilitate the delivery of holistic care, encompassing a combination of medication, dietary consultations, and psychological support. The significance of educating patients with psychosomatic disorders in the ability to name and recognise emotions and cope with stress is also emphasised. In cases where patients are experiencing symptoms that are deteriorating as a result of anxiety or stress, the utilisation of mind-body therapies, cognitive-behavioral therapies (including hypnosis, meditation, various forms of relaxation or biofeedback), is recommended (Chey et al. 2020). The International Foundation for Gastrointestinal Disorders also recommends diaphragmatic/ab-

dominal breathing techniques, progressive muscle relaxation by tensing and then relaxing different muscle groups, and visualisation/positive imagery techniques to facilitate the imaginative process of envisioning oneself in a calm, quiet and relaxing place. By focusing on a particular place, the patient is able to divert their attention away from disturbing thoughts. It is imperative that patients with IBS invest time in acquiring knowledge about the condition, identifying potential triggers for symptoms, and engaging in the relaxation exercises that have been outlined. This approach enables them to take proactive, constructive, and innovative measures to enhance their ability to cope with and manage their symptoms effectively (Zeichner 2005).

It is imperative to adopt effective coping mechanisms to manage the stress and anxiety that may be precipitated by IBS. It has been demonstrated that breathing exercises, meditation and yoga can assist in the reduction of stress and tension. Relaxation techniques can be used in two ways: as a supplement to pharmacological therapy or as an alternative when medication is not sufficiently effective (Chey et al. 2020; Zeichner 2005).

7. Limitations of current therapies

It is worth highlighting that the therapeutic options currently employed in the treatment of IBS are associated with several limitations. There is a paucity of long-term data on the effects of probiotics as a therapeutic treatment and the adverse events associated with it. It is imperative to acknowledge that the efficacy of probiotic therapy is contingent upon the specific strain used, the dosage administered and the duration of the treatment regimen. To date, these factors have not been optimised for IBS subtypes. The safety profile is also not unclear, particularly in the case of long-term therapy (Umeano et al. 2024; Almonajjed et al. 2025). A further limitation of the IBS therapies in current use is the relatively small sample size and the limited duration of the studies. This limits the capacity to derive robust conclusions, particularly with regard to the efficacy of probiotics in managing different subtypes of IBS. Further research is required with larger populations and longer durations in order to evaluate the long-term efficacy of probiotics and to determine their effect on different subtypes of IBS (Ruiz-Sánchez et al. 2024; Almonajjed et al. 2025). A considerable number of medications, comprising antispasmodics,

antidepressants and several novel agents, have been observed to offer only a marginal improvement in IBS symptoms. It is important to note that the alleviation of gastrointestinal symptoms does not necessarily result in a substantial enhancement of the patient's overall quality of life. This underscores the necessity for a holistic approach (Talley 2003; Sainsbury and Ford et al. 2011; Hammerle et al. 2008; Brenner et al. 2024). Certain medications, notably older antidepressants such as tricyclic antidepressants (TCAs), have been observed to induce significant adverse effects that can potentially restrict their utilisation, especially in individuals suffering from IBS, who may already be afflicted by gastrointestinal discomfort (Wall et al. 2011; Lacy et al. 2009). Despite the evidence that brain-gut behaviour therapy (BGBT) is efficacious in the amelioration of IBS symptoms and quality of life, access to this therapy is limited by a paucity of trained practitioners, patient time constraints and cost. Furthermore, clinicians may also have a lack of awareness of the specific nature of BGBT and its distinction from general psychotherapy, which may potentially hinder referrals (Brenner et al. 2024). Personalised treatment strategies that consider individual symptom profiles, dietary factors, and psychological aspects are often required, but their implementation can be complex (Sainsbury and Ford et al. 2011).

8. Future perspectives

The integration of advanced omics technologies and machine learning techniques has the potential to significantly enhance future research in the comprehensive analysis of microbiome composition and the identification of therapeutic targets. Combined with next-generation sequencing (NGS) technologies, such as shotgun metagenomics, provide deeper insights into the structure and function of the GM. The application of advanced techniques (metatranscriptomics or metabolomics) holds promise in enhancing our comprehension of the microbial functional pathways that contribute to the pathogenesis of IBS. These methods provide a more detailed picture of the complex interactions between the microbiome and host physiology, helping to identify novel therapeutic targets necessary to develop effective microbiome-targeted interventions. The use of these instruments has the capacity to expedite the identification of diagnostic biomarkers, improve patient risk assessment, and refine the predic-

tion of treatment response in IBS (Fukui et al. 2020; Jacobs and Lagishetty et al. 2023; Aggeletopoulou and Triantos 2024). Current research on IBS is confronted with a number of methodological challenges. The majority of studies rely on the sequencing of the 16S ribosomal RNA subunit (rRNA) gene, which offers only genus-level resolution and fails to provide functional insight into the microbiome. In contradistinction to NGS, more advanced techniques, such as shotgun metagenomic sequencing and RNA sequencing, offer greater sensitivity, resolution and deeper understanding of microbial structure and function. Furthermore, most studies focus on stool samples, which may not fully represent the microbiome of other intestinal regions, such as the small intestine or mucosal layer. In addition, while some studies assess the microbiota at different time points, most are limited to two measurements, making it difficult to track changes in microbiota and metabolites over time, especially during disease exacerbations or remission (Aggeletopoulou and Triantos 2024; Ankersen and Weimers 2021; Ek and Reznichenko 2015; Mars and Yang 2020; Meydan and Afshinnekoo 2020).

9. Conclusions

Irritable bowel syndrome is a multifactorial gastrointestinal disorder involving numerous factors, including genetic predisposition, psychoenvironmental factors, and alterations in the composition of GM. Scientific reports published in recent years indicate that GM play a crucial role in the development and progression of IBS, particularly in cases of reduced levels of certain GM species, a condition referred to as dysbiosis. The involvement of GM in numerous processes associated with IBS has been well-documented, including nutrient absorption in the intestines, immune response regulation, the functioning of the GBA, and mucosal immune regulation. However, due to the substantial interindividual variability, it remains challenging to identify a universal GM composition in IBS. The efficacy of the available treatment methods is a contentious issue. The therapeutic approach to IBS should be personalised, and future research should focus on the search for microbial species that might be used as biomarkers for IBS. These biomarkers would help to differentiate between the subtypes of this gastrointestinal disorder.



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Conflict of interest

The authors do not report any financial or personal connections with other persons or organizations, which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

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