Andrew Thomas, MBBS, Annie Thomas, PhD,
and Madeline Butler-Sanchez, MS (Dietetics)

CME/CE/MOC Offering

Dietary Modification for the Restoration of Gut Microbiome and Management of Symptoms in Irritable Bowel Syndrome

Abstract: *Irritable bowel syndrome (IBS) is a functional gastrointestinal disorder leading to chronic debilitating issues. A healthy diet plays an integral role in maintaining the gut microbiota equilibrium, thus promoting digestive health. The structure and function of gut microbiota are affected by genetics and environmental factors, such as altered dietary habits, gastroenteritis, stress, increased use of alcohol and drugs, and medication use. Whereas there are various management approaches cited in the literature to manage symptoms of IBS, the purpose of this article is to focus on dietary options that will restore the gut microbiome and help in managing IBS symptoms. Some of the diets that are discussed in this article include a low-FODMAP (fermentable oligosaccharides, disaccharides, monosaccharides, and polyols) diet, gluten-free/wheat-free diet, high-fiber diet, dietary and herbal supplements (psyllium, peppermint oil), and probiotics/prebiotics/synbiotics. The clinical practice guidelines recommended by the American College of Gastroenterology outlines evidence-based dietary recommendations for patients with IBS to manage symptoms. Recent advancements in the dietary management of IBS highlighting the use of a patient-centered, personalized nutrition approach along with lifestyle changes, pharmacological therapies, and psychosocial and behavioral interventions are also reviewed and discussed.*

Keywords: dietary modification; irritable bowel syndrome; gut microbiota; symptom control

> A microbe-rich biodiverse environment may likely promote the development of healthy gut microbiota and lower the risk of various diseases.

Introduction

Irritable bowel syndrome (IBS) is a chronic digestive disorder affecting people in the United States and worldwide.[1,2] It is a significant public health concern. IBS carries a huge burden of care across the globe, but countries like the United States are hugely affected. The cost and the burden of the disorder is increasing rapidly.[1,3,4] According to the National Institute of Diabetes, Digestive and Kidney Diseases, about 12% of people in the United States have IBS.[2] Current evidence indicates that along with genetics, environmental factors play an eminent role in causing IBS.[3,5] Although the etiology is not clearly understood, some of the environmental factors that cause IBS are unhealthy dietary habits, acute gastroenteritis, stress, smoking, and alcohol intake.[5-10] People across the world are moving toward adopting unhealthy dietary patterns such as consumption of fried and other food

DOI:10.1177/15598276211012968. Manuscript received October 13, 2020; revised March 13, 2021; accepted April 8, 2021. From Bharati Vidyapeeth Medical College, Pune, India, and University of Illinois Health Sciences System, Chicago, Illinois (Andrew T); Marcella Niehoff School of Nursing, Loyola University Chicago, Illinois (Annie T); and Parkinson School of Health Sciences and Public Health, Loyola University Chicago, Illinois (MB-S). Address correspondence to: Andrew Thomas, MBBS, University of Illinois Health Sciences System, Clinical Sciences Building, 840, Southwood Street, Suite 148, Chicago, IL 60612; e-mail: andrewt905@gmail.com.

items abundant in fat, protein, and sugar. This can alter the gut microbiota.[3,11,12] There are various management approaches cited in the literature to restore gut microbiota and manage symptoms of IBS.[1,3,10,11] An evidence review conducted on the management approaches reported that dietary, lifestyle, medical, and behavioral interventions, individualized and holistic, are very effective in maintaining the host microbiota and in managing IBS.[1]

There is increasing evidence for the influence of host diet and its alteration of the gut microbiome, which may play a role in the pathogenesis of digestive disorders such as IBS.[3,4,6,11] It is important to discuss the role of various evidence-based dietary interventions that will help in restoring and maintaining the gut microbiota, thus facilitating support in symptom control in patients with IBS. The primary objective of this article is to address how various dietary interventions will help restore gut microbiota to normal. Some of the current research on dietary interventions in IBS lack rigor in research design and evidence and therefore present a challenge for clinicians. There are evidence-based studies that prove the clinical efficacy of specific diet interventions for symptom management in IBS. This article aims to pool, condense, and present evidence-based data on dietary interventions that are beneficial in IBS. Given the variations of the gut microbiome in each individual and unique human responses to dietary interventions in IBS, this article will also address the importance of utilizing precision nutrition/personalized nutrition approaches in managing IBS.

What Is Irritable Bowel Syndrome?

IBS is a functional gastrointestinal (GI) disorder characterized by abdominal pain or discomfort, bloating, and changes in the bowel movements that occur in the absence of other organic GI disease.[2,5,9,10] IBS is often associated with somatic conditions (pain syndromes, migraine, overactive bladder), psychiatric conditions (anxiety, depression), and visceral hypersensitivity.[9] IBS is the most prevalent type of functional GI disorder. The common subtypes of IBS are IBS with constipation (IBS-C), IBS with diarrhea (IBS-D), IBS with mixed bowel habits (IBS-M), and unsubtyped IBS.[2,9,10] IBS can affect all individuals, although it is more common in women and in individuals <50 years old. However, many older adults also get affected.[5,10] The disorder presents diagnostic and treatment challenges, and it can be debilitating for many patients, contributing to a disturbed quality of life.[5,9]

Gut Microbiota and Factors That Shape Gut Microbiota

Gut microbiota are the organisms that reside in the GI tract.[7,11,13] Gut microbiota comprise a changing ecosystem, containing trillions of bacteria.[7] The GI microbiota offer many benefits to the host. They perform a variety of functions: maintenance of the integrity of the mucosal barrier or shaping the intestinal epithelium; protection against pathogens, intestinal and systemic immune modulation; regulation of host immunity, host nutrient metabolism, and nutrient absorption; drug metabolism; and synthesis of essential vitamins, enzymes, and amino acids.[11,14] In the GI tract, the energy is derived, and the health of the host is maintained through production of metabolites from ingested food and also from host carbohydrates. It then undergoes processes such as fermentation and sulfate reduction. Intestinal mucus is also a great source of carbohydrates as an energy source for the gut microbiota.[13,14]

The components of the intestinal barrier play a major role in protecting the host immune system and in shaping the microbiota composition of the GI tract. These components are epithelial and mucosal layers (physical), enzymes and microbial proteins (biochemical), and IgA and epithelia-associated immune cells (immunological).[14] The alteration in the gut microbiota composition or dysbiosis can cause many intestinal and extraintestinal disease conditions.[11] Gut microbes must be adapted to a certain type of lifestyle to survive because of a limited quantity of biochemical niches in the GI tract.[14] A microbe-rich biodiverse environment may likely promote the development of healthy gut microbiota and lower the risk of various diseases.[15]

The coexisting healthy host and microbiota relationship is important to the health of individuals and to prevent disease development.[13,14] The factors that are known to shape the microbiota composition are genetics, dietary habits, lifestyle choices, use of antibiotics, smoking habits, medical illnesses and surgery, immunity status, mental well-being, living arrangements (urban or rural), and seasonal variations.[7,11,12,14-16]

Current research reports that diet is one of the key modulators that shape the gut microbiota composition and the structure of the gut microbiome. It directly influences host homeostasis and biological processes in the GI tract.[7,11] Albeit the role of various diets in gut microbiota is still largely unknown, the excessive consumption of either animal-based or plant-based diets has been reported to cause alterations of gut microbiota in humans.[14] There are studies that show the influence of an unhealthy diet on gut microbiota alteration. However, the detrimental effects are largely associated with the use of food additives, obesity, and metabolic diseases.[3,11,12,14]

Role of the Microbiota in the Etiology and Pathophysiology of IBS

The precise etiology of IBS is unknown.[16,17] IBS is categorized as a heterogeneous disorder, with a multifactorial pathogenesis.[16,18] Evidence shows that an imbalance in the gut microbiota (gut dysbiosis) contributes to the pathogenesis of IBS.[11,14,16] Some of the known etiological factors that predispose individuals to IBS are genetic and epigenetic factors, most notably an identified mutation of SCN5A, stress-induced nervous system and endocrine

changes, immune dysregulation, altered gut-brain interactions, altered gut microbiota and gut mucosal inflammation, and dietary influences.[5,17,19] Acute gastroenteritis following exposure to various pathogens may trigger small-intestinal bacterial overgrowth, causing IBS.[6]

The pathophysiological changes can cause maladaptive shifts in the gut microbiota, leading to increased epithelial permeability, inflammation, mucosal barrier dysfunction, visceral hypersensitivity, enteric nervous system and immune system dysfunction, imbalanced neurotransmitters and hormones, and altered gut-brain axis.[5,16,18] Altered gut microbial composition or dysbiosis can result in endotoxemia, insulin resistance, systemic inflammation, adiposity, irritable bowel disorder, colorectal cancer, metabolic disorders, nonalcoholic fatty liver diseases, and more.[13] A review conducted by Staudacher et al[20] reported that the worst symptoms in IBS are caused by the dysbiosis of the luminal and mucosal colonic microbiota precipitated by the reduction in species of bifidobacterial count.

Role of Dietary Patterns in IBS

Diet plays an important role in shaping the composition and the structure of the gut microbiome. Dietary alterations can quickly affect the host-microbiota equilibrium, leading to GI disorders such as IBS.[3,11,14,21] The structure and function of gut microbiota are heavily influenced by diets rich in a complex mixture of fats and simple sugars.[12] Studies report that dietary shifts that comprise high-fat, high animal protein, and high sugar diets contribute to microbiome dysbiosis and the severity of IBS.[8,11] Studies also report a strong association between imbalanced carbohydrate intake affecting host health and IBS pathogenesis.[8,11] Additionally, increased consumption of fiber-rich food, especially polyphenols, indicates improved health outcomes through synergic and mediating effects.[22] A healthy dietary pattern contributes to maintaining the gut microbiota-host equilibrium. The alterations in lifestyle changes can cause gut dysbiosis, leading to IBS and various other disease conditions.[17,21,23,24]

Dietary Strategies to Restore Gut Microbiota in IBS

The diet that is ingested interacts with the gut bacteria and the gut endocrine cells. Experimental trials have reported that dietary alterations can induce large and temporary microbial shifts within 24 hours.[1,17,21,25] The healthy diet we consume acts as a prebiotic, favoring the growth of certain types of bacteria. The prebiotics stimulate good bacteria to grow in the gut.[25] It is believed that the symptoms that the patients experience in IBS are a result of low density of gut endocrine cells and low number of stem cells.[17,25,26] When nutrients enter the lumen of the GI tract, the endocrine cells release various GI hormones and control several GI functions.[26] The diet that is ingested can act as a substrate for gut bacteria metabolism, releasing several by-products. These by-products then act on the stem cells, eventually decreasing the gut stem cells and endocrine cells.[17,20,25,26] A study conducted by Mazzawi et al[26] reports that the density of the endocrine cells in the large intestine are affected by the type of diet consumed. Therefore, dietary modification can change the gut microbiota, normalize the density of endocrine cells, and help recover the malfunctioning endocrine cells toward improvement of IBS symptoms.[17,21,25,26] In addition to dietary modification, the American College of Gastroenterology (ACG) and Canadian Association of Gastroenterology have outlined various management approaches, such as pharmacological agents, cognitive behavioral therapy, hypnotherapy, exercise, and alternative therapies, to improve IBS symptoms.[4,10,27]

This review article will focus on using various diets as well as other therapies such as the use of probiotics, prebiotics, and/or synbiotics and peppermint oil supplements to restore gut microbiome and help in achieving symptom control in IBS.

Low-FODMAP (Fermentable Oligosaccharides, Disaccharides, Monosaccharides, and Polyols) Diet

A diet low in short-chain fermentable carbohydrates is an effective and internationally accepted regimen and the first choice of diet for the management of symptoms in IBS.[25,28-36] FODMAP stands for fermentable oligosaccharides, disaccharides, monosaccharides, and polyols. The restriction of various types of fermentable carbohydrates such as oligosaccharides (fructans, galacto-oligosaccharides [GOS]), disaccharides (lactose), monosaccharides (fructose when in excess of glucose), and polyols (sorbitol, mannitol) significantly improve GI symptoms in patients with IBS.[36,37]

A high-FODMAP diet contains more fermentable carbohydrates that are poorly absorbed, highly osmotic (draws water into the gut), and are rapidly fermented by intestinal bacteria resulting in gut symptoms in patients with IBS.[25,38] Several studies have reported that FODMAP restriction led to improvement of symptoms such as abdominal pain, bloating, constipation, diarrhea, abdominal distension, and flatulence in 50% to 80 % of patients.[29,31,32,35,36] The FODMAP categories that cause symptoms, the mechanism of action each FODMAP category, and the food types that might trigger symptoms in IBS are presented in Table 1.

The effects of high-FODMAP diet to cause exacerbation of GI symptoms in IBS have been researched in detail and documented in the literature.[29,35,36,39,40] Carbohydrates play a significant role in causing symptoms in IBS. Carbohydrates constitute the major components of human diet. The digestion and absorption of carbohydrates in the small intestine is influenced by factors such as the amount of hydrolase enzymes, presence of digestive diseases, transit time, and the dose consumed.[36] The absence of luminal enzymes capable of hydrolyzing the glycosidic bonds in the

Table 1.

High-FODMAP Categories, Mechanism of Action, and Major Food Sources to Avoid.[a]

Categories	Mechanism of action	Major food sources
Oligosaccharides		
Fructans (oligo-fructose, inulin, fructo-oligosaccharides)	The fructans cannot hydrolyze the fructose bond food in the small intestine. It enters the colon causing fermentation by colonic bacteria and causes IBS symptoms	Wheat, onion, garlic
Galacto-oligosaccharides	The galactose-galactose molecules in the small intestine also cannot be hydrolyzed in the small intestine and cause similar symptoms as fructans	Chickpeas (including hummus), lentils, pulses (red kidney beans)
Inulin-type fructans and galacto-oligosaccharides	These offer prebiotic function and, therefore, provide health benefits	
Disaccharides		
Lactose	Lactose is a disaccharide of glucose and galactose. It is absorbed in the brush border of the proximal small intestine. When there is no function or reduced activity of the lactase enzymes, lactose is not broken down to glucose and galactose. The lactose remains malabsorbed, causing increased production of short-chain fatty acids, methane, and hydrogen, leading to increased gas production, flatulence, and distension of both the small and large intestines	Milk, milk products
Monosaccharides		
Fructose (in high concentrations or excess of glucose)	Fructose, in the presence of glucose is readily absorbed from the small intestine. However, more fructose content in the diet can lead to malabsorption causing pain, abdominal distension, and bloating in patients with visceral hypersensitivity and IBS	Large volumes of fruit juice (watermelon, pineapple, pears, apple), high-fructose corn syrup; mango, fig, honey (contains excess of glucose)
Polyols		
Sorbitol and mannitol	Polyols are reduced-calorie carbohydrate sweeteners or sugar alcohols. These polyols are slowly absorbed from the small intestine, but when they reach the large intestine, they induce an osmotic effect (drawing water content into the bowel). Can cause laxative effect in addition to gut bacteria fermentation and gas production	Prunes, mushrooms, avocado, cauliflower, and apples; the substance added to sugar-free foods such as pudding and gelatin
Xylitol, isomalt	Same action as sorbitol and mannitol	Artificial sweetener added in some sugar-free chewing gums, mints, and sweets

Abbreviation: FODMAP, fermentable oligosaccharides, disaccharides, monosaccharides, and polyols; IBS, irritable bowel syndrome.
[a]Martinez et al[12] and El-Salhy et al.[25]

complex carbohydrates is reported as one of the factors contributing to the poor absorption of high-FODMAP diet.[37] Some short-chain fermentable carbohydrates are absorbed in the small intestine. The absence or reduced activity of intestinal brush border enzymes such as lactase and epithelial glucose transporter-2 and glucose transporter-5 cause poor absorption of the FODMAP diet as well.[36,37] The long-chain nonstarch polysaccharides contribute to a major

proportion of the nondigestible carbohydrates. Some disaccharides and monosaccharides remain unabsorbed from the small intestine.[35,36] The undigested and unabsorbed carbohydrates enter the large intestine, where they are fermented. It is reported that up to 40 g/d of undigested and or unabsorbed carbohydrate enters the colon. Short-chain carbohydrates with fewer monomers (eg, oligofructose) are fermented faster and produce a large volume of gas, leading to bloating and other GI issues.[36,40] The unabsorbed fructose, polyols, and lactose lead to increased small intestinal water. In the colon, the unabsorbed carbohydrates, mainly the fructans and the oligosaccharides, are fermented, leading to increased production of hydrogen and methane, thus leading to accumulation of gas. This can further result in luminal distension, causing functional GI symptoms.[34,35]

The presence of visceral hypersensitivity causing symptoms in IBS has been reported in the literature. The luminal distension caused by the intake of a high-FODMAP diet may aggravate symptoms in patients with visceral hypersensitivity.[36,39] Visceral hypersensitivity, or an increased perception of stimuli originating from the viscera, is a distinctive feature in IBS.[39] The mediators released during intestinal inflammation (histamine, tryptase, or Adenosine triphosphate (ATP) and the central factors such as altered neuroendocrine responses, altered gut-brain axis, and psychiatric comorbidities are the factors that contribute to the pathogenesis of visceral hypersensitivity in IBS.[39] Visceral hypersensitivity can cause increase in the luminal water and GI distension. This can induce severe GI symptoms, such as bloating, flatulence, abdominal pain, diarrhea, and functional GI symptoms, in patients with IBS.[36,39,40]

Recent studies have indicated that a diet high in FODMAPs is highly osmotic, and it will draw more water into the gut. This promotes an increase in the colonic water volume in the distal small bowel and the proximal colon, thus intensifying the intestinal motility.[34,36,38] Some FODMAPs affect the small-intestinal transit time, therefore reducing the time for the small intestinal absorption to happen. This will increase the time and the availability of carbohydrates for colonic fermentation, thus producing more gas in the colon and increased flatulence.[36,40]

Although the mechanism is not fully understood, research studies have reported that the low-FODMAP diet reduces the production of luminal short-chain fatty acids (SCFAs) and total stool SCFA concentration.[36,40] An association between IBS symptomatology and higher concentrations of SCFAs in the stool has been studied, especially in those patients with increased visceral hypersensitivity.[36,40] The normal mechanism is that the human intestinal microbiota ferment the indigestible dietary fiber content in the large intestine and release SCFAs as by-products, including acetate, butyrate, or propionate. These are either absorbed by the gut epithelium to carry out various physiological processes or excreted in the feces.[41,42] The by-product, butyrate, mainly serves as the primary energy source for the colonocytes, the epithelial cell of the colon. The colonocyte metabolism basically helps shape the gut microbiota.[36,41,42] The reduced availability of fermentable substrate and shift in the abundance of bacterial taxa involved in SCFA production and/or cross-feeding reactions are believed to be the reason for the reduction in stool SCFA concentration in patients on a low-FODMAP diet regimen.[36,41,42]

Studies report that patients with IBS develop severe symptoms because of a low density of gut endocrine cells.[25,26] A diet low in fermentable carbohydrates and insoluble fiber has been shown to increase the number of endocrine cells in the gut and to foster greater improvement in the digestive symptoms.[25,26]

Recent studies have revealed that a low-FODMAP diet affects the gut microbiota and metabolome (total number of metabolites present within a cell, tissue, and organ).[36] Long-term intake of a low-FODMAP diet is known to adversely affect the intestinal microbiota composition and functions.[29,36] The significant reduction in the dietary intake of various categories of FODMAP may alter the natural prebiotic effects of these categories. Despite known beneficial effects of the low-FODMAP diet for symptom control, some FODMAP categories such as oligosaccharides, fructans (fructo-oligosaccharides and inulin), and GOS are known to act as prebiotics. A prebiotic is defined as "a substrate that is selectively utilized by the microorganism, conferring a health benefit, (p. 1,3)."[41] Prebiotics promote maintenance and restoration of beneficial gut organisms, such as the *Bifidobacterium* and *Lactobacillus* species.[29,36,41] The low-FODMAP diet can cause nutritional inadequacies and imbalances as a result of a considerable reduction in the intake of prebiotics such as fructans and GOS.[36] A few studies have reported a decrease in the fecal *Bifidobacterium* species after following a 2- to 4-week low-FODMAP dietary regimen. Although beneficial to reduce IBS symptoms, the low-FODMAP diet minimizes sufficient intake of prebiotics. The detrimental effect of a low-FODMAP diet on beneficial bacterial groups, such as the *Bifidobacterium* and *Lactobacillus* species or overall gut bacteria, as well as on gut health needs further investigation.[25,29,36,40,41]

Evidence suggests that the low-FODMAP diet causes a major reduction in substrate available for colonic fermentation.[29,43] The long-term dietary elimination of all FODMAPs is not recommended in IBS because it can alter the composition and functioning of gut microbiota and cause a reduction in specific bacterial groups (eg, *Bifidobacterium*) or the overall microbiota community.[24,36,43] The FODMAP restriction is therefore recommended for short-term use only. Patients are counseled to liberalize the use after symptom improvement.[25,29,37]

The ACG outlines the FODMAP diet categories the patient must avoid consuming.[35] Among the food items are fruits (apples, apricots, peaches, pears, watermelon, grapes, mangoes);

vegetables (artichokes, asparagus, cauliflower, lima beans, mushrooms, peas, beets, broccoli); artificial sweeteners (sorbitol, mannitol, isomaltose); high-lactose milk, dairy, whey; nondairy milk alternatives (soy milk, coconut milk); fructans (fructose and sweeteners such as honey and agave apples); starchy foods (bread, pasta, semolina); and galactans (plant-based protein such as black-eyed peas, chick peas, kidney beans).[35]

Some types of polyols in the FODMAP diet promote gut health and, therefore, are recommended in IBS. Polyols have been shown to increase the *Bifidobacterium* bacteria and therefore support maintenance of gut health.[44] Polyols are naturally occurring sugar alcohols found in a variety of fruits, vegetables, and sugar-free sweeteners. The polyols that promote good gut health are lactitol, isomalt, xylitol, and erythritol. However, consuming large quantities of polyols such as sorbitol and mannitol can aggravate the symptoms. Polyols used as sweeteners in sugar-free diet products, therefore, must be consumed with caution by patients with IBS.[44]

Despite the benefits of a low-FODMAP diet for symptom control in IBS, it can cause nutritional deficiencies and alteration in the gut microbiota. Therefore, the role of an expert dietitian is imperative during dietary management.[25,26,34,37,45] A personalized and culturally tailored dietary guidance by a registered dietitian/nutritionist (RDN) is essential for identifying the specific low-FODMAP food groups for symptom control and quality outcomes.[25,26,45] The dietary plan must include replacing the high FODMAP content from the same food group with low FODMAPs. Dietary counseling must focus on integrating a balanced FODMAP diet to include adequate nutrients from carbohydrates, proteins, fats, vitamins, minerals, and other important nutrients.[25,26,37,38]

The implementation of a low-FODMAP diet is divided into 3 phases: the FODMAP restriction phase, the FODMAP reintroduction/rechallenge phase, and the FODMAP personalization and maintenance phase. For symptom control, all 3 phases must be strictly practiced under the supervision of a nutritionist/dietitian. In addition to the comprehensive dietary counseling offered by the RDN, various dietary resources incorporating an up-to-date list of alternative FODMAP food items must be utilized. Some of these resources that can complement the individualized counseling are the low-FODMAP diet sheets, smartphone applications and cookbooks, and patient-led dietary websites.[26,37] These resources combined with the individualized dietary counseling will enhance dietary adherence in the low-FODMAP regimen in all 3 phases.[26,37,44]

During the initial visit, the RDN completes a nutrition assessment and works with the patient to establish a healthy and reasonable weight goal. A diet history tool can be used to gather information regarding the food groups that induce or relieve symptoms, food groups already avoided, regularly consumed diet, and alternative food preferences. The RDN also must assess the psychosocial, cultural, ethnic, and religious background to plan a diet that is consistent with the patient's beliefs.[25,38] After the assessment and the goals for treatment have been established, the low-FODMAP dietary implementation will begin.[25,38] The patient assessment details, phases of low-FODMAP implementation, and guidelines are presented in Table 2.

Although the efficacy of the low-FODMAP diet for the successful control of symptoms in IBS has been studied and reported in the literature, it can pose some challenges to patients.[25,46-48] Adhering to a low-FODMAP schedule may be quite challenging for patients, mainly because of the risk for nutritional deficiencies and gut microbiota alteration and issues related to psychosocial adjustments. Adhering to a low-FODMAP diet requires psychosocial adjustments, such as in social dining and dining out and limited food choices while traveling.[25,37,38] For better symptom control, patients must, however, adhere to dietary guidelines during each phase.[25,37,38] If patients do not achieve symptom control after adhering to FODMAP restriction and reintroduction, the low-FODMAP diet may have been ineffective and, therefore, discontinuation is recommended.[25,37,38] For those patients, some therapeutic approaches are recommended. These include the use of prebiotics and immunoglobulins, medications to manage symptoms, cognitive behavioral therapy, and gut-directed hypnotherapy. A low-FODMAP diet supplemented with a microbiota-targeted therapy has also been used and found to be beneficial in patients with IBS.[25,27,37,49]

Gluten-Free and Wheat-Free Diet

Many studies report that patients with IBS experience symptom control when following a gluten-free and wheat-free diet.[29,34,50-52] Gluten is an immunogenic protein found primarily in grains such as wheat, rye, and barley. Gluten is known to cause celiac disease—an inflammatory, autoimmune disease—in genetically susceptible individuals. It is found that a gluten-containing diet also contributes to the pathogenesis of IBS. Although the exact mechanism is unknown, it can cause altered bowel barrier function in patients with IBS-D.[50,51] Some patients with IBS report worsening of symptoms with wheat and wheat products.[50,51] Rej and Sanders[50] report that gluten may not be the only contributing factor, but that other wheat compounds such as amylase and trypsin inhibitors (ATIs) or wheat germ agglutinins (WGA's) found in wheat molecules can trigger inflammation in the intestines and inflammatory responses in immune cells, thus leading to impaired intestinal cell permeability.[31,50] Current evidence indicates that a gluten-free and wheat-free diet offer symptom relief in patients who may have gluten-sensitive IBS.[31,50]

Studies report that it is important to weigh the benefits and disadvantages when planning on initiating a gluten-free diet for patients with IBS.[29,31,34,50-53] A prospective study carried out on 41 individuals demonstrated improvement

Table 2.

Phases to Implement Low-FODMAP[12,25] Diet in Irritable Bowel Syndrome.[a]

Low-FODMAP diet: implementation phases[25,38,48,52]			
Preassessment and dietary counseling	**Phase 1: FODMAP restriction**	**Phase 2: FODMAP Rechallenge/ reintroduction**	**Phase 3: FODMAP Maintenance /Personalization**
Assessment			
Baseline assessment Anthropometry (height, weight) and body mass index - Biochemical tests to exclude other comorbidities - Gather past medical history, family history, nutritional history Clinical assessment - Start with confirming the diagnosis Use Rome IV criteria for diagnosing IBS and Rome IV diagnostic criteria to confirm IBS subtypes[25] - Perform comprehensive symptom assessment for gastrointestinal symptoms, stool output, quality of life Some symptom assessment tools used are the following: Global symptom questions (yes/no questions), Gastrointestinal Symptom Rating Scale, Visual Analogue Scale for IBS, IBS Severity Scoring System, Bristol Stool Form Scale, Short Form 36 Health Survey, IBS Quality of Life Questionnaire[25] Dietary assessment Quantitative: assessment of current nutrients and FODMAP intake, food diary, 24-hour recall or diet history, food frequency questionnaire that includes FODMAP intake Qualitative: food that aggravates symptoms, food preferences, eating patterns, food access, availability, dietary restriction, use of nutritional supplements.[12,25] Dietary counseling: a registered dietitian/nutritionist specialized in training in FODMAPs will provide counseling During initial visit: - Explain the effects of FODMAP restriction - Counsel regarding the food sources of each FODMAP category, how to incorporate FODMAP restriction into daily lifestyle, adherence to FODMAP diet, food-related social activities, day-to-day shopping, etc - Tailor counseling to specific symptoms and different IBS subgroups to evaluate the effectiveness of low-FODMAP diet - Counsel regarding the importance of maintaining quality[25,48,52]	The food items that are high in FODMAP are restricted and substituted with small portions of moderate- or low-FODMAP alternatives This phase is maintained for 3-6 weeks. Many people will notice improvement in symptoms by week 2. If symptoms have improved by week 4, patients move to reintroduction phase The degree of symptom improvement is variable for patients. If the symptoms have not improved, consider other treatment options[22,38] One of the goals during this phase is to increase the variety of diet to ensure compliance and reduce nutritional deficiencies associated with prolonged restriction There may be situations where all the FODMAP categories need not be restricted; therefore, dietary counseling is tailored to each case[25,52] Assess for clinical response. Use various symptom assessment tools and IBS Quality of Life Questionnaire[25]	FODMAPs are slowly introduced into the patient's diet to test tolerance and exacerbation of symptoms This phase is usually commenced after 2-6 weeks on the restrictive phase of the low-FODMAP diet After reassessing for the symptoms and diet, counsel regarding FODMAP re-introduction Patients are instructed to remain on the strict low-FODMAP diet while completing the challenges[38] One challenge is completed at a time, and each specific food is tested every 3 days[38] For each food challenge, only 1 food from a new FODMAP category is recommended[52] Counsel patients to identify triggers and doses (quantity) that induce symptoms with each dietary challenge[25] The food groups that are frequently consumed are challenged first[11] Instruct patients to document the symptom types, symptom control, and severity of symptoms with each challenge[25,38] After all the FODMAP categories have been trialed, patients can follow an individualized, modified version of the low-FODMAP diet[38,52]	After identifying the trigger foods, patients continue to take other high-FODMAP foods that are tolerated. The triggers are eliminated altogether during this phase The dietitian recommends a personalized dietary plan to meet nutritional needs The personalization will focus on a diverse healthy diet that is enjoyable and not restricting the psychosocial aspects (eg, dining out, other socializing events etc)[25,38] Inform that a certain degree of symptoms is normal[11,52] Patients are advised to return to normal diet gradually to prevent abrupt worsening of symptoms If FODMAP restriction failed to resolve symptoms, other dietary approaches such as administration of prebiotics must be utilized[25] In the long-term, counsel on personalization with a less restrictive and diverse diet. Exclude the FODMAPs that induce symptoms[25]

Abbreviations: FODMAP, fermentable oligosaccharides, disaccharides, monosaccharides, and polyols; IBS, irritable bowel syndrome.

[a]Rome IV criteria: presence or recurrent abdominal pain (on average at least 1 day per week in past 3 months associated with 2 or more of (1) pain related to defecation; (2) a change in frequency of stool; and (3) a change in the form (appearance of stool).[25] IBS subtypes: IBS with diarrhea, IBS with constipation, IBS with mixed symptoms, IBS unclassified/unsubtyped.[25]

of symptoms when they were put on a gluten-free diet for 6 weeks. There was a reduction in the IBS Symptom Severity Score from 286 to 131 ($P < .001$). However, the gluten-free diet presented some drawbacks when it was administered to individuals without IBS.[51] An expert consensus meeting and the reviews of studies conducted by gastroenterologists and dietitian specialists suggests the use of a low-FODMAP diet, gluten-free diet, and a wheat-free diet as dietary therapies for IBS. The consensus team recommends a dietary approach that is individualized and directed by a registered dietitian.[31] However, another study by Dieterich and Zopf[29] reported that patients with IBS were found to rarely describe ingestion of gluten as a trigger in causing symptoms. Additionally, wheat products contain fructans, a FODMAP food category that is recommended to be avoided by patients with IBS.[29] Therefore, the symptom improvement in IBS cannot be correctly correlated with the reduction of either a low-FODMAP diet or gluten-free diet.[29] This raises the question of how effective a gluten-free diet is in the management of IBS.

A significant reduction in the gut bacterial concentrations of *Bifidobacterium adolescentis* and *Faecalibacterium prausnitzii* are also found with a gluten-free and low-FODMAP diet. These bacterial groups help in maintaining the gut ecosystem, thus promoting GI health.[29,31,50] A gluten-free diet is also known to cause nutritional deficiencies in patients with IBS.[29] A systematic review and meta-analysis of randomized controlled trials (RCTs) conducted by Dionne et al[52] reported that some patients with IBS may have an intolerance to gluten, despite not having celiac disease. That might prompt the clinicians to recommend a gluten-free diet in IBS. The authors in this review reported that conclusive evidence is still lacking to recommend a gluten-free diet for symptom control in IBS.[52] Therefore, high-quality RCTs are required to evaluate the effect of a gluten-free diet for its safe use in IBS.

High-Fiber Diet

The emerging increase in chronic digestive diseases is reported to be related to the progressive loss of microbial diversity. It is attributed to the decline in the consumption of dietary fiber.[54,55] The health benefits of a high-fiber diet and its role in shaping the colonic microbiota are well investigated. The microbiota-accessible carbohydrates that are found in dietary fibers are fermented and used by the colon bacteria as a source of nourishment.[14,45]

Polyphenols are a vital constituent of fiber-rich foods. They have antibacterial and anti-inflammatory properties. Polyphenols can change the makeup of gut bacteria in a beneficial way by increasing the concentrations of *Bifidobacteria* and *Lactobacillus*, thus aiding in symptom control in IBS.[22] The restoration of beneficial bacteria and microbiota by following healthy dietary patterns might prevent the progression of chronic diseases such as IBS.[55]

A systematic review of 3 randomized clinical trials showed that fiber supplements were beneficial in IBS-C.[54] The authors, however, recommended a larger and increased number of RCTs for generating stronger evidence that supports the beneficial effects of fiber-rich diets in restoring gut microbiome and managing IBS-related symptoms.[54]

Fiber Supplements (Psyllium). Psyllium is a form of fiber made from the husk of plant seeds—namely *Plantago ovata*. It is found to be very effective in the management of symptoms in IBS.[54,56] The fermentation of soluble fiber such as psyllium in the gut can have an impact on gut function. It is believed that the fermentation of the soluble fiber such as psyllium can increase SCFA production, such as butyrate, which can provide energy for colonic mucosal cells and act as an anti-inflammatory agent. These SCFAs or other fermentation products can also act as a substrate for gut bacteria.[56] The prebiotic effect of psyllium can change the composition of the gut microbiome and promote gut health.[54,56] The high-water holding capacity and bulk-forming capability of psyllium can improve stool consistency in IBS-D.[57] The same mechanism increases stool frequency in patients with IBS-C.[56,57] Psyllium can be considered as one of the first-line therapies because of its low cost and easy availability.

Probiotics, Prebiotics, and Synbiotics

Studies report that alteration of gut microbiota plays a beneficial role in reversing the pathophysiology of IBS.[17,58,59] This could be achieved by enhancing the host and gut microbiota equilibrium with the use of probiotics, prebiotics, and synbiotics.[17,32,58-62]

Probiotics

Probiotics are live strains of microorganisms that when administered in adequate amounts confer a health benefit on the host.[59,60,62] The mechanisms through which probiotics exert their beneficial effects in IBS are not fully known.[60,62] However, in a survey among clinicians, most believed that probiotics are a good therapeutic option for IBS, and more than 90% recommended probiotics.[62] Probiotics, mainly the *Bifidobacterium* and *Lactobacillus* species, are known to induce beneficial modulation of altered gut microbiota by reducing the number of competing pathogens. The modulation effects are accomplished through mechanisms such as the production of antimicrobial substances and by interfering in the intestinal mucosal adhesion.[59] The probiotic strains that are found to be effective in reducing IBS symptoms, if used alone or as a multistrain formulation, are *Bifidobacterium* species (*Bifidobacterium lactis*, *Bifidobacterium infantis*, etc), *Lactobacillus* species, *Streptococcus* species, *Saccharomyces boulardii* (yeast), and *Lactobacillus rhamnosus GG*.[17,59,62]

A randomized, placebo-controlled trial conducted by Staudacher et al[32] evaluated the effect of a multistrand probiotics formulation with low FODMAP for symptom control in

patients with IBS.[32] The coadministration of the multistrain probiotic with a low-FODMAP diet increased the numbers of the *Bifidobacterium* species compared with placebo. *Bifidobacteria* provided immunomodulatory effects and prevented clinical symptoms in IBS. The total IBS severity score was significantly lower in patients who received a low-FODMAP diet and probiotics.[32] The low-FODMAP diet was found to cause a reduction in *Bifidobacteria*. The study recommended use of multistrain *Bifidobacterium*-containing probiotics with a low-FODMAP diet to restore *Bifidobacteria* in IBS.[32]

There are multiple research studies and meta-analyses that evaluate the effects of single probiotic strains and combinations of probiotic strains in IBS.[17,32,59,62] A systematic review with meta-analysis of 53 RCTs performed by Ford et al[62] reported that certain combinations of probiotics or specific species and strains have beneficial effects on global IBS symptoms and abdominal pain. Among the combinations, Lac Clean gold and the 7-strain combination of 3 *Bifidobacterium*, 3 *Lactobacillus*, and 1 *Streptococcus* were associated with significant improvements in global symptoms and abdominal pain scores.[62] Among individual probiotics, *Lactobacillus plantarum* DSM 9843, *Escherichia coli* DSM 17252, and *Streptococcus faecium* had benefits on global symptoms.[62] However, it remains unclear which specific combination, species, or strain must be used in IBS. Definitive evidence on the efficacy of probiotics in IBS is yet to be established.[17,62] It is recommended that a personalized probiotics therapy guided by individual microbiota profiling may offer promising benefits to patients with IBS in the future.

Prebiotics

Prebiotics are substrates that are selectively utilized by host microorganisms, conferring health benefits.[62] According to the Food and Agriculture Organization of the United Nations, prebiotics are nonviable food components that confer a health benefit on the host through the modulation of microbiota.[17] Prebiotics may serve as an alternative treatment in IBS because they provide the metabolizable substrates for growth of specific bacteria, thus affecting the composition and function of the gut microbiota.[17,59] Prebiotics are effective in modifying the individual strains and species of gut microbiota.[59] Many sources of prebiotics exist. These are lactulose, fructo-oligosaccharides, GOS, trans-GOS, inulin and reflux starch, cellulose and hemicellulose, pectin, and other natural sources from foods.[17,58,59,61,62] Natural sources of prebiotics include cereals, fruits, green vegetables, and plants.[17,59] The 2 most investigated prebiotics categories are inulin-type fructans and GOS.[61] Currently, other novel classes of prebiotics such as arabinoxylan-oligosaccharides, manno-oligosaccharides, resistant starch, and xylo-oligosaccharides are also being investigated to test their efficacy in IBS treatment.[58]

Although the beneficial effects of prebiotics in IBS have been studied, there is little evidence for their use in IBS. Therefore, researchers recommend more trials to establish their efficacy and safe use in IBS.[17,58,59,62] A systematic review and meta-analysis of 11 randomized, placebo-controlled trials was conducted by Wilson et al[58] to evaluate the effect of prebiotics on global response, GI symptoms, quality of life, and gut microbiota in adult patients with IBS and other functional bowel disorders. The review reported that patients who received prebiotics experienced no differences in the severity of abdominal pain, bloating, flatulence, and quality of life compared with the placebo group.[58] The flatulence severity improved with non–inulin-type fructan prebiotics at doses ≤6 g/dL. The non–inulin-type fructan prebiotics in higher doses had no effect. The inulin-type fructans worsened the flatulence. Prebiotics did not significantly affect anxiety or depression scores. The variations in prebiotic types affected symptom improvement in IBS. The prebiotic supplementation of β-GOS and pectin powder significantly increased fecal bifidobacterial counts. The type of prebiotics, dose, and duration did not influence the overall symptoms in IBS, but differences were seen in individual symptoms.[58] In summary, robust clinical trials are needed to evaluate the efficacy of novel prebiotics and non–inulin-type fructans for symptom control in IBS.

Synbiotics

Synbiotics are the combination of synergistically acting probiotics and prebiotics.[17,59,62] Synbiotics selectively stimulate growth and survival of beneficial organisms or activate the metabolism of intestinal microbiota, thus contributing to beneficial effects in IBS.[59,62] Some examples of synbiotics used in IBS with beneficial effects are yogurt with acacia fiber plus *B lactis*, inulin plus *B lactis*, and *S boulardii* plus ispaghula husk.[17] Although synbiotics are safe for consumption, the randomized controlled clinical trials that evaluated their effectiveness in patients with IBS have shown mixed results.[17,59,61,62] A review of RCTs conducted by Rodiño-Janeiro et al[59] that focused on interventions targeting the gut microbiota reported several beneficial effects of synbiotics. With various combinations of synbiotics, patients reported significant improvement in bowel habits, satisfaction with bowel habits, and a total IBS quality-of-life score.[59]

The systematic review and meta-analysis of 53 RCTs that evaluated the efficacy of prebiotics, probiotics, and synbiotics in IBS reported that there are relatively few studies and there is insufficient evidence to support the use of prebiotics and synbiotics in the treatment of IBS.[62] Because there are only a relatively limited number of clinical trials conducted on synbiotics therapies in IBS patients, more data from RCTs are needed to support the benefits of synbiotics in the management of IBS.

Peppermint Oil Supplements

Peppermint oil has been found to be effective for symptom control in patients with IBS and other GI disorders.[63-66]

Despite a lack of strong evidence to support its effectiveness from high-quality RCTs, it has shown great promise for treating IBS.[63,66] Peppermint oil is derived from the peppermint plant, *Mentha* × *piperita*, which grows mostly in North America and Europe. It has been found to affect upper- and lower-GI physiology.[63,64] The physiological effects of peppermint oil are smooth muscle relaxation via calcium channel blockade, direct enteric nervous system effects, visceral sensitivity modulation via transient receptor potential cation channels, 5-hydroxy tryptamine antagonism effect and alleviating properties on functional GI disorders, k-opioid receptor modulation causing decrease in severity of abdominal pain, antimicrobial/antifungal effects, anti-inflammatory activities, and modulation of psychosocial distress.[63-66]

Studies have investigated the safety and efficacy of various formulations of peppermint oil in IBS.[63,65,66] A meta-analysis of 12 randomized clinical trials with a total of 835 patients revealed that peppermint oil is a safe and effective therapy for pain and global symptoms in IBS.[65] The US Food and Drug Administration recommends a novel peppermint oil formulation designed for sustained release in the small intestine. This formulation is reported to be a more safe and effective form for the relief of abdominal pain/discomfort and IBS severity, with very mild adverse effects.[63,66] A randomized, double-blind, placebo-controlled trial evaluated the efficacy and tolerability of this novel formulation of peppermint oil designed for sustained release in the small intestine in patients with IBS-M and IBS-D types.[66] The trial was carried out for 4 weeks. The study revealed that the sustained release formulation in the small intestine provided rapid relief of IBS symptoms. There was a decrease in the Total IBS Symptom Score from baseline by 19.6% at 24 hours and a 40% decrease after 4 weeks of treatment.[66] The patients in this trial had greater improvement in multiple individual GI symptoms as well as severe or unbearable symptoms.[66] The enteric-coated sustained release formulation of peppermint oil in the small intestine was well tolerated with fewer adverse effects.[66]

A randomized, double-blind trial performed on 190 patients with IBS that evaluated the efficacy and safety of small-intestinal-release peppermint oil and ileocolonic-release peppermint oil found that neither form of peppermint oil produced statistically significant reductions in abdominal pain response or overall symptoms relief in 8 weeks.[63] However, the small-intestinal-release peppermint oil produced greater improvements in abdominal pain and IBS severity compared with ileocolonic-release peppermint oil and placebo. The authors recommended the use of small-intestinal-release peppermint oil with moderate efficacy in the treatment of IBS.[63]

Peppermint oil is used successfully for several GI and other disorders, and fewer adverse effects have been reported in the clinical trials. It is well tolerated by most patients with IBS, with occasional reports of heartburn, nausea, belching (with or without a minty taste), headache, altered anal sensation, sensitive urethra, peppermint oil–scented stool, and abdominal cramps.[63-66] It is recommended to discontinue if the patient continues to experience severe headache, palpitations, diarrhea, abdominal cramps, tightness of chest, bloating, or muscle cramps.[63]

The mechanism related to the direct effect of peppermint oil on the gut microbiome in IBS remains unclear. The immune-modulating, anti-inflammatory, anti-microbial, antiviral, antifungal, and antioxidant effects of peppermint oil have been documented in the literature.[63-65] The antispasmodic effect of peppermint oil offers significant symptom relief in IBS.[63,64] However, the other GI effects of peppermint oil that contribute to the clinical benefits are not entirely known.[64] Overall, the balancing effects of peppermint oil would be beneficial in maintaining or restoring the gut-host microbiome equilibrium and preventing/reversing the pathogenesis of IBS.

Clinical Practice Guidelines for Dietary Management in IBS

The ACG published the first clinical practice guideline in 2021 for the management of IBS.[4] The guideline focused on addressing key issues related to the diagnosis and management of IBS, including dietary management and recommended evidence-based guidelines for clinical practice. The quality of evidence for each category of diagnosis and management in the guideline is expressed as "high," "moderate," "low or very low." For the high evidence level, it is stated that the estimate of effect is unlikely to change with new research and data. However, for the moderate, low, and very low levels of evidence, the estimate of effect is reported to be uncertain and might change.[4] The strength of recommendation for each diagnosis and management category is categorized as either "strong" or "conditional." If the recommendation is labeled as strong, it is safe for most patients to opt for that recommendation. If the recommendation is labeled as conditional, patients can follow the recommended course of action, but different choices may be appropriate for some patients. An expert discussion is recommended in this situation to arrive at a decision based on the patient's values and preferences.[4]

The ACG's clinical practice guideline recommends the following dietary options for the management of symptoms in IBS[4]:

- Limited trial of a low-FODMAP diet in patients with IBS to improve global symptoms (conditional recommendation; very low quality of evidence). The rationale for this recommendation is the complexity of a low-FODMAP diet, potential for

nutritional deficiencies, and time and resources needed for dietary counseling in the 3 phases, requiring the services of a trained dietitian during each phase of the FODMAP treatment. Although the use of a low-FODMAP diet is not fully recommended in the ACG's clinical practice guideline, the expert committee recommends future trials to evaluate its efficacy and safe use in IBS.

- Use soluble, but not insoluble, fiber to treat global IBS symptoms (strong recommendation; moderate quality of evidence). Most experts recommend 25 to 35 g of total fiber intake per day.
- Use peppermint to provide relief of global IBS symptoms (conditional recommendation; low quality of evidence). Although the dose range, frequency, and forms of peppermint oil are not mentioned, the RCTs that evaluated the effectiveness of peppermint used 182 mg of peppermint oil and recommended to use the enteric-coated form that is released in the small bowel for greater benefits.
- Suggest against using probiotics for the treatment of global symptoms in IBS (conditional recommendation, very low quality of evidence). Further research is recommended, given the importance of probiotics to restore the intestinal microbiome in IBS.

As mentioned above, the most recent clinical practice guideline published by the American Gastroenterology Association mentioned the use of a low-FODMAP diet with individualized dietary counseling, high-fiber (soluble-fiber) diet, peppermint oil, and probiotics as the evidence-based dietary options for symptom management in IBS.[4] Albeit not integrated in the recent ACG guideline published in 2021, the use of a gluten-free diet, prebiotics, and synbiotics has also been studied by the researchers and recommended for IBS management.[4,10,52,58,62] An ACG monograph published in 2018 had included these dietary options in addition to the 2021 dietary guidelines to manage symptoms in IBS.[4,10] Although not supported with stronger evidence to use these dietary options per the 2018 monograph, the safety and efficacy of these dietary options to manage symptoms in IBS have been studied and reported. The researchers recommended more trials to validate the current findings before the clinicians can recommend a gluten-free diet, prebiotics, and synbiotics for managing IBS.[4,10,52,58,62]

Personalized Nutrition Approach for Managing IBS

The gut microbiota profile of each individual is unique.[67,68] It is shaped in early life. The personal and healthy environment of host and gut microbiota remains stable in adulthood. However, it differs between individuals and is influenced by environmental factors such as stress, dietary changes, antibiotic use, lifestyle changes, obesity, and so on.[55,68] Diet is one of the major factors that play a significant role in determining the makeup of the gut microbiome, structural integrity, protection against pathogens, digestive functions, immune modulation, and so on.[7,67] This realization of different human responses to dietary changes contributing to the unique composition and function of gut microbiota led researchers to recommend personalized nutrition approaches in IBS.[68,69] The symptoms of IBS greatly affect the quality of life patients.[4] Although the details provided in this review offer insight into the dietary management options in IBS, the simplified algorithm for clinical practice recommended by Moayyedi et al[70] proposes to use a personalized consultation to educate and reassure patients with IBS symptoms. The authors propose a patient-centered, step-by-step approach by considering the nutritional needs, cost, culture, and values of the patient.[70]

As more research studies are yet to be conducted on this, it will be interesting to see if the precision nutrition approaches will prevent, reverse, or correct alteration of gut microbiota in IBS.

Conclusion and Recommendations

Dietary patterns and environmental factors help shape our gut microbiota from infancy to adulthood. This review article highlights how the restoration of gut microbiota to a healthier state can help achieve symptom control in IBS, specifically by adhering to various diets and supplements, such as a low-FODMAP diet, a gluten-free/wheat-free diet, high-fiber diet, probiotics/prebiotics/synbiotics, and peppermint oil. IBS-specific clinical practice guidelines offer insight into an evidence-based dietary regimen that is found to be effective for patients with IBS. The novel, personalized nutrition management approach may be integral for optimizing care and for quality outcomes in patients with IBS. A strong physician-patient relationship from diagnosis to management is the key to success in IBS management. Therefore, it is recommended to integrate personalized lifestyle changes, dietary modifications, pharmacological and psychological interventions, and a combination of therapies for the best clinical response in IBS.

In conclusion, healthy lifestyle choices and a healthy dietary routine from childhood through adulthood, as integral components of lifestyle medicine, help maintain the structure and functions of the gut microbiome.

CME/CE Article Quiz

American College of Lifestyle Medicine (ACLM) members can earn FREE CME/CE credit by reading this approved CME/CE article and successfully completing the online CME/CE activity. Non-members can earn CME/CE for $40 per article. Visit lifestylemedicine.org to join the ACLM.

Instructions.

1. AJLM CME/CE Articles and Quizzes are offered online only through the American College of Lifestyle Medicine and are accessible at lifestylemedicine.org/store. ACLM Members can enroll in the activity, complete the quiz, and earn this CME/CE for free. Non-members will be charged $40 per article.
2. A Passing score of 80% or higher is required in order to be awarded the CME/CE credit.

Authors' Note

All authors contributed equally to develop this manuscript. This is a review article, and the literature search was carried out by accessing the databases. Therefore, an approval from the Institutional Review Board was not necessary.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Ethical Approval

Not applicable, because this article does not contain any studies with human or animal subjects.

Informed Consent

Not applicable, because this article does not contain any studies with human or animal subjects.

Trial Registration

Not applicable, because this article does not contain any clinical trials.

ORCID iD

Andrew Thomas https://orcid.org/0000-0001-5494-9623 AJLM

References

1. Chey WD, Kurlander J, Eswaran S. Irritable bowel syndrome: a clinical review. *JAMA*. 2015;313:949-958.
2. Loyola University Chicago. Definition and facts for irritable bowel syndrome. Accessed April 15, 2021. https://www-niddk-nih-gov.flagship.luc.edu/health-information/digestive-diseases/irritable-bowel-syndrome/definition-facts#common
3. Hills RD, Pontefract BA, Mishcon HR, Black CA, Sutton SC, Theberge CR. Gut microbiome: profound implications for diet and disease. *Nutrients*. 2019;11:1613. doi:10.3390/nu11071613
4. Lacy BE, Pimentel M, Brenner DM, et al. ACG clinical guideline: management of irritable bowel syndrome. *Am J Gastroenterol*. 2021;116:17-44. doi:10.14309/ajg.0000000000001036
5. Enck P, Aziz Q, Barbara G, et al. Irritable bowel syndrome. *Nat Rev Dis Primers*. 2016;2:16014. doi:10.1038/nrdp.2016.14
6. Pimentel M, Lembo A. Microbiome and its role in irritable bowel syndrome. *Dig Dis Sci*. 2020;65:829-839. doi:10.1007/s10620-020-06109-5
7. Rinninella E, Cintoni M, Raoul P, et al. Food components and dietary habits: keys for a healthy gut microbiota composition. *Nutrients*. 2019;11:2393. doi:10.3390/nu11102393
8. Seo YS, Lee HB, Kim Y, Park HY. Dietary carbohydrate constituents related to gut dysbiosis and health. *Microorganisms*. 2020;8:427.
9. Defrees DN, Bailey J. Irritable bowel syndrome: epidemiology, pathophysiology, diagnosis, and treatment. *Prim Care*. 2017;44:655-671.
10. Ford AC, Moayyedi P, Chey WD, et al. American College of Gastroenterology monograph on management of irritable bowel syndrome. *Am J Gastroenterol*. 2018;113(suppl 2):1-18.
11. Zangara MT, McDonald C. How diet and the microbiome shape health or contribute to disease: a mini-review of current models and clinical studies. *Exp Biol Med (Maywood)*. 2019;244:484-493. doi:10.1177/1535370219826070
12. Martinez KB, Leone V, Chang EB. Western diets, gut dysbiosis, and metabolic diseases: are they linked? *Gut Microbes*. 2017;8:130-142. doi:10.1080/19490976.2016.1270811
13. Pushpanathan P, Mathew GS, Selvarajan S, Seshadri KG, Srikanth P. Gut microbiota and its mysteries. *Indian J Med Microbiol*. 2019;37:268-277. doi:10.4103/ijmm.IJMM_19_373
14. Thursby E, Juge N. Introduction to the human gut microbiota. *Biochem J*. 2017;474:1823-1836. doi:10.1042/BCJ20160510
15. Tasnim N, Abulizi N, Pither J, Hart MM, Gibson DL. Linking the gut microbial ecosystem with the environment: does gut health depend on where we live? *Front Microbiol*. 2017;8:1935. doi:10.3389/fmicb.2017.01935
16. Menees S, Chey W. The gut microbiome and irritable bowel syndrome. *F1000Res*. 2018;7:F1000 Faculty Rev-1029. doi:10.12688/f1000research.14592.1
17. Chong PP, Chin VK, Looi CY, Wong WF, Madhavan P, Yong VC. The microbiome and irritable bowel syndrome—a review on the pathophysiology, current research and future therapy. *Front Microbiol*. 2019;10:1136. doi:10.3389/fmicb.2019.01136
18. Singh R, Salem A, Nanavati J, Mullin GE. The role of diet in the treatment of irritable bowel syndrome: a systematic review. *Gastroenterol Clin North Am*. 2018;47:107-137. doi:10.1016/j.gtc.2017.10.003
19. Holtmann GJ, Ford AC, Talley NJ. Pathophysiology of irritable bowel syndrome. *Lancet Gastroenterol Hepatol*. 2016;1:133-146. doi:10.1016/S2468-1253(16)30023-1
20. Staudacher HM, Whelan K. Altered gastrointestinal microbiota in irritable bowel syndrome and its modification by

diet: probiotics, prebiotics and the low FODMAP diet. *Proc Nutr Soc*. 2016;75:306-318. doi:10.1017/S0029665116000021

21. David LA, Maurice CF, Carmody RN, et al. Diet rapidly and reproducibly alters the human gut microbiome. *Nature*. 2014;505:559-563. doi:10.1038/nature12820
22. Mena P, Bresciani L. Dietary fibre modifies gut microbiota: what's the role of (poly)phenols? *Int J Food Sci Nutr*. 2020;71:783-784.
23. Mohajeri MH, Brummer RJM, Rastall RA, et al. The role of the microbiome for human health: from basic science to clinical applications. *Eur J Nutr*. 2018;57(suppl 1):1-14. doi:10.1007/s00394-018-1703-4
24. Rej A, Aziz I, Tornblom H, Sanders DS, Simrén M. The role of diet in irritable bowel syndrome: implications for dietary advice. *J Intern Med*. 2019;286:490-502. doi:10.1111/joim.12966
25. El-Salhy M, Hatlebakk JG, Hausken T. Diet in irritable bowel syndrome (IBS): interaction with gut microbiota and gut hormones. *Nutrients*. 2019;11:1824. doi:10.3390/nu11081824
26. Mazzawi T, Hausken T, Gundersen D, El-Salhy M. Dietary guidance normalizes large intestinal endocrine cell densities in patients with irritable bowel syndrome. *Eur J Clin Nutr*. 2016;70:175-181. doi:10.1038/ejcn.2015.191
27. Moayyedi P, Andrews CN, MacQueen G, et al. Canadian Association of Gastroenterology Clinical Practice Guideline for the Management of Irritable Bowel Syndrome (IBS). *J Can Assoc Gastroenterol*. 2019;2:6-29.
28. Hustoft TN, Hausken T, Ystad SO, et al. Effects of varying dietary content of fermentable short-chain carbohydrates on symptoms, fecal microenvironment, and cytokine profiles in patients with irritable bowel syndrome. *Neurogastroenterol Motil*. 2017;29(4). doi:10.1111/nmo.12969
29. Dieterich W, Zopf Y. Gluten and FODMAPS—sense of a restriction/when is restriction necessary? *Nutrients*. 2019;11:1957. doi:10.3390/nu11081957
30. Su H, Li YT, Heitkemper MM, Zia J. Effects of low-FODMAPS diet on irritable bowel syndrome symptoms and gut microbiome. *Gastroenterol Nurs*. 2019;42:150-158. doi:10.1097/SGA.0000000000000428
31. Rej A, Avery A, Ford AC, et al. Clinical application of dietary therapies in irritable bowel syndrome. *J Gastrointestinal Liver Dis*. 2018;27:307-316. doi:10.15403/jgld.2014.1121.273.avy
32. Staudacher HM, Lomer MCE, Farquharson FM, et al. A diet low in FODMAPs reduces symptoms in patients with irritable bowel syndrome and a probiotic restores *Bifidobacterium* species: a randomized controlled trial. *Gastroenterology*. 2017;153:936-947. doi:10.1053/j.gastro.2017.06.010
33. Schumann D, Klose P, Lauche R, Dobos G, Langhorst J, Cramer H. Low fermentable, oligo-, di-, mono-saccharides and polyol diet in the treatment of irritable bowel syndrome: a systematic review and meta-analysis. *Nutrition*. 2018;45:24-31. doi:10.1016/j.nut.2017.07.004
34. Barrett JS. How to institute the low-FODMAP diet. *J Gastroenterol Hepatol*. 2017;32(suppl 1):8-10. doi:10.1111/jgh.13686
35. American College of Gastroenterology. Low FODMAP diet. Accessed April 15, 2021. https://gi.org/topics/low-fodmap-diet/
36. Staudacher HM, Whelan K. The low FODMAP diet: recent advances in understanding its mechanisms and efficacy in IBS. *Gut*. 2017;66:1517-1527. doi:10.1136/gutjnl-2017-313750
37. Mehtab W, Agarwal A, Singh N, Malhotra A, Makharia GK. All that a physician should know about FODMAPs. *Indian J Gastroenterol*. 2019;38:378-390. doi:10.1007/s12664-019-01002-0
38. Phillips W, Walker J. When a registered dietitian becomes the patient: translating the science of the low FODMAP diet to daily living. *Pract Gastroenterol*. 2018;175:20-37.
39. Deiteren A, de Wit A, van der Linden L, De Man JG, Pelckmans PA, De Winter BY. Irritable bowel syndrome and visceral hypersensitivity: risk factors and pathophysiological mechanisms. *Acta Gastroenterol Belg*. 2016;79:29-38.
40. Staudacher HM, Irving PM, Lomer MCE, Whelan K. Mechanisms and efficacy of dietary FODMAP restriction in IBS. *Nat Rev Gastroenterol Hepatol*. 2014;11:256-266. doi:10.1038/nrgastro.2013.259
41. Gibson GR, Hutkins R, Sanders ME, et al. Expert consensus document: the International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of prebiotics. *Nat Rev Gastroenterol Hepatol*. 2017;14:491-502. doi:10.1038/nrgastro.2017.75
42. de la Cuesta-Zuluaga J, Mueller NT, Álvarez-Quintero R, et al. Higher fecal short-chain fatty acid levels are associated with gut microbiome dysbiosis, obesity, hypertension and cardiometabolic disease risk factors. *Nutrients*. 2018;11:51. doi:10.3390/nu11010051
43. Harvie RM, Chisholm AW, Bisanz JE, et al. Long-term irritable bowel syndrome symptom control with reintroduction of selected FODMAPs. *World J Gastroenterol*. 2017;23:4632-4643. doi:10.3748/wjg.v23.i25.4632
44. Lenhart A, Chey WD. A systematic review of the effects of polyols on gastrointestinal health and irritable bowel syndrome. *Adv Nutr*. 2017;8:587-596. doi:10.3945/an.117.015560
45. Whelan K, Martin LD, Staudacher HM, Lomer MCE. The low FODMAP diet in the management of irritable bowel syndrome: an evidence-based review of FODMAP restriction, reintroduction and personalisation in clinical practice. *J Hum Nutr Diet*. 2018;31:239-255. doi:10.1111/jhn.12530
46. Halmos EP, Gibson PR. Controversies and reality of the FODMAP diet for patients with irritable bowel syndrome. *J Gastroenterol Hepatol*. 2019;34:1134-1142. doi:10.1111/jgh.14650
47. Nanayakkara WS, Skidmore PM, O'Brien L, Wilkinson TJ, Gearry RB. Efficacy of the low FODMAP diet for treating irritable bowel syndrome: the evidence to date. *Clin Exp Gastroenterol*. 2016;9:131-142. doi:10.2147/CEG.S86798
48. Tuck C, Barrett J. Re-challenging FODMAPs: the low FODMAP diet phase two. *J Gastroenterol Hepatol*. 2017;32(suppl 1):11-15. doi:10.1111/jgh.13687
49. Ooi SL, Correa D, Pak SC. Probiotics, prebiotics, and low FODMAP diet for irritable bowel syndrome—what is the current evidence? *Complement Ther Med*. 2019;43:73-80. doi:10.1016/j.ctim.2019.01.010
50. Rej A, Sanders DS. Gluten-free diet and its "cousins" in irritable bowel syndrome. *Nutrients*. 2018;10:1727. doi:10.3390/nu10111727
51. Aziz I, Trott N, Briggs R, North JR, Hadjivassiliou M, Sanders DS. Efficacy of a gluten-free diet in subjects with irritable bowel syndrome-diarrhea unaware of their HLA-DQ2/8 genotype. *Clin Gastroenterol Hepatol*. 2016;14:696-703.e1. doi:10.1016/j.cgh.2015.12.031
52. Dionne J, Ford AC, Yuan Y, et al. A systematic review and meta-analysis evaluating the efficacy of a gluten-free diet and a low FODMAPs diet in treating symptoms of irritable bowel syndrome. *Am J Gastroenterol*. 2018;113:1290-1300. doi:10.1038/s41395-018-0195-4
53. Paduano D, Cingolani A, Tanda E, Usai P. Effect of three diets (low-FODMAP, gluten-free and balanced) on irritable bowel

syndrome symptoms and health-related quality of life. *Nutrients*. 2019;11:1566. doi:10.3390/nu11071566

54. Rao SSC, Yu S, Fedewa A. Systematic review: dietary fibre and FODMAP-restricted diet in the management of constipation and irritable bowel syndrome. *Aliment Pharmacol Ther*. 2015;41:1256-1270. doi:10.1111/apt.13167
55. Requena T, Martínez-Cuesta MC, Peláez C. Diet and microbiota linked in health and disease. *Food Funct*. 2018;9:688-704. doi:10.1039/c7fo01820g
56. Moayyedi P, Quigley EMM, Lacy BE, et al. The effect of fiber supplementation on irritable bowel syndrome: a systematic review and meta-analysis. *Am J Gastroenterol*. 2014;109:1367-1374. doi:10.1038/ajg.2014.195
57. Halmos EP. When the low FODMAP diet does not work. *J Gastroenterol Hepatol*. 2017;32(suppl 1):69-72. doi:10.1111/jgh.13701
58. Wilson B, Rossi M, Dimidi E, Whelan K. Prebiotics in irritable bowel syndrome and other functional bowel disorders in adults: a systematic review and meta-analysis of randomized controlled trials. *Am J Clin Nutr*. 2019;109:1098-1111. doi:10.1093/ajcn/nqy376
59. Rodiño-Janeiro BK, Vicario M, Alonso-Cotoner C, Pascua-García R, Santos J. A review of microbiota and irritable bowel syndrome: future in therapies. *Adv Ther*. 2018;35:289-310. doi:10.1007/s12325-018-0673-5
60. Barbara G, Cremon C, Azpiroz F. Probiotics in irritable bowel syndrome: where are we? *Neurogastroenterol Motil*. 2018;30:e13513. doi:10.1111/nmo.13513
61. Harris LA, Baffy N. Modulation of the gut microbiota: a focus on treatments for irritable bowel syndrome. *Postgrad Med*. 2017;129:872-888. doi:10.1080/00325481.2017.1383819
62. Ford AC, Harris LA, Lacy BE, Quigley EMM, Moayyedi P. Systematic review with meta-analysis: the efficacy of prebiotics, probiotics, synbiotics and antibiotics in irritable bowel syndrome. *Aliment Pharmacol Ther*. 2018;48:1044-1060. doi:10.1111/apt.15001
63. Weerts ZZRM, Masclee AAM, Witteman BJM, et al. Efficacy and safety of peppermint oil in a randomized, double-blind trial of patients with irritable bowel syndrome. *Gastroenterology*. 2020;158:123-136. doi:10.1053/j.gastro.2019.08.026
64. Chumpitazi BP, Kearns GL, Shulman RJ. Review article: the physiological effects and safety of peppermint oil and its efficacy in irritable bowel syndrome and other functional disorders. *Aliment Pharmacol Ther*. 2018;47:738-752. doi:10.1111/apt.14519
65. Alammar N, Wang L, Saberi B, et al. The impact of peppermint oil on the irritable bowel syndrome: a meta-analysis of the pooled clinical data. *BMC Complement Altern Med*. 2019;19:21. doi:10.1186/s12906-018-2409-0
66. Cash BD, Epstein MS, Shah SM. A novel delivery system of peppermint oil is an effective therapy for irritable bowel syndrome symptoms. *Dig Dis Sci*. 2016;61:560-571. doi:10.1007/s10620-015-3858-7
67. Rinninella E, Raoul P, Cintoni M, et al. What is the healthy gut microbiota composition? A changing ecosystem across age, environment, diet, and diseases. *Microorganisms*. 2019;7:14. doi:10.3390/microorganisms7010014
68. Kolodziejczyk AA, Zheng D, Elinav E. Diet-microbiota interactions and personalized nutrition. *Nat Rev Microbiol*. 2019;17:742-753. doi:10.1038/s41579-019-0256-8
69. Mills S, Lane JA, Smith GJ, Grimaldi KA, Ross RP, Stanton C. Precision nutrition and the microbiome part II: potential opportunities and pathways to commercialisation. *Nutrients*. 2019;11:1468. doi:10.3390/nu11071468
70. Moayyedi P, Mearin F, Azpiroz F, et al. Irritable bowel syndrome diagnosis and management: a simplified algorithm for clinical practice. *United European Gastroenterol J*. 2017;5:773-788. doi:10.1177/2050640617731968