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REVIEW

Low-FODMAP Diet for Irritable Bowel Syndrome: Is It Ready for Prime Time?

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Abstract Irritable bowel syndrome (IBS) is a chronic gastrointestinal disease, which adversely affects the quality of life. Its prevalence has been reported to be around 10–15 % in North America and constitutes the most common cause for gastroenterology referral. Unfortunately, the pathophysiology of IBS is not completely understood. Not surprisingly, the management strategies can leave the patients with inadequate symptom control, making IBS a debilitating gastrointestinal syndrome. Dietary interventions as a treatment strategy for IBS have been recently evaluated. One such intervention includes dietary restriction of fermentable oligo-, di-, and monosaccharides and polyols (FODMAPs). FODMAPs define a group of short-chain carbohydrates that are incompletely absorbed in small intestine and later fermented in the colon. Evidence in the form of randomized controlled trials and observational studies have evaluated the mechanism of action and efficacy of low-FODMAP diet. This dietary intervention has showed promising results in symptom reduction in IBS patients. However, latest trials have also shown that the low-FODMAP diet is associated with marked changes in gut microbiota specifically reduction in microbiota with prebiotic properties. Implications of such changes on gastrointestinal health need to be further evaluated in future trials.

Keywords IBS · FODMAP · Irritable bowel syndrome · Fermentable carbohydrates

Introduction

Irritable bowel syndrome (IBS) is a common condition characterized by chronic gastrointestinal symptoms like abdominal discomfort or pain and altered bowel habits, with many patients also complaining about bloating and abdominal distention in the absence of any organic cause [1]. Population-based studies have estimated the prevalence of IBS symptoms to be as high as 10–15 % in North America [2–6]. Women are affected twice as common as men, mostly with a lower socioeconomic status and age <50 years [3, 7].

Despite the benign nature of this functional illness, IBS patients have remarkably decreased quality of life. They have lower work productivity, higher rates of absenteeism, and may even experience social isolation or even stigmatization [8, 9]. IBS is the second most common cause of work absenteeism after common cold [10]. Although only about 15 % of patients seek medical attention [11, 12], IBS is responsible for a very large number of primary care visits and is the most common cause of gastroenterology referrals [13]. This translates into an exponential burden on health care: The annual costs (both direct and indirect) for managing IBS patients is estimated to be between $15 and 30 billion [14, 15].

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Unfortunately, the pathophysiology of IBS is not completely understood. Some of the mechanisms involved in pathogenesis include visceral hypersensitivity, altered microbial colonization of the gastrointestinal tract, food intolerance, increased gastrointestinal fermentation, altered motility, changes in microbiota, and brain-gut axis dysregulation [16–20]. Considering the potential role of food or specific trigger foods in symptom exacerbation, many of the affected individuals implement dietary changes. Monsbakken et al. [21] showed that around 60 % patients had self-limited the daily intake of perceived culprit foods and 12 % patients had done so to the extent of risking nutritional deficiency in the long run.

Recently, a significant amount of research has been focused on dietary intervention for IBS patients to control symptoms and improve quality of life. This has led to the development of a novel diet-restricting fermentable oligo-, di-, and monosaccharides and polyols (FODMAPs). This review discusses efficacy, mechanism of action and potential pitfalls in low-FODMAP diet in the light of current evidence.

Dietary Sources of FODMAP

FODMAPs define a group of fermentable carbohydrates including oligosaccharides (fructans and galactans), disaccharides (lactose), monosaccharides (fructose in excess of glucose), and polyols (sorbitol, mannitol etc.). These short-chain carbohydrates are fermented in the colon because of incomplete absorption in the small bowel, which may either lack specific absorptive pathways (e.g., polyols), have a limited absorptive capacity (e.g., fructose), or cannot enzymatically digest specific oligosaccharides (e.g., fructans).

Fructose

Sources of fructose in diet include fruits, honey, and especially important in our modern diet—high-fructose corn syrup (Table 1). Two pathways have been described well in the literature for the absorption of fructose. The high-capacity pathway utilizes GLUT-2 carriers which co-transport fructose with glucose [22]. The low-capacity pathway utilizes GLUT-5 carrier mediated facilitated diffusion [23]. Fructose malabsorption usually occurs when fructose is present in excess of glucose, in which case it depends on the low-capacity pathway for absorption, allowing only limited absorption with resulting colonic fermentation. Based on hydrogen breath testing, the prevalence of fructose malabsorption may be as high as 40 % in the general population and increases with rising fructose load [24, 25].

Lactose

By definition, milk and dairy products are the primary source of lactose (Table 1). While essentially all humans express lactase during infancy, enzyme expression changes around weaning with a loss in lactose level and resulting lactose malabsorption. The prevalence of lactose malabsorption varies between different ethnic groups and may

Table 1 High FODMAPs food sources

	Fructose (higher than glucose)	Lactose	Oligosaccharides (fructans/galactans)	Polyols
Fruits	Apples, pears, peaches, watermelon, mango, raisins,			Apples, pears, cherries, lychee, apricots, coconut milk, peaches, plums, prunes, watermelon
Vegetables			Onions, garlic, asparagus, artichokes, Brussels sprout, broccoli, cabbage, leeks, okra, beetroot, chicory	Avocado, butternut pumpkin, mushrooms, cauliflower
Dairy		Milk (regular and low fat), ice cream		
		Yoghurt (regular and low fat), soft and fresh cheese (cottage, ricotta)		
Grains			Wheat, rye, barley (when eaten in large amounts), chickpeas, lentils, red kidney beans, baked beans	
Sweeteners	Honey, high-fructose corn syrup			Sorbitol, mannitol, xylitol, isomalt

exceed 80 % in individuals of African descent [26]. While ingestion of lactose-containing food often causes significant symptoms in these individuals, Yang et al. [27] reported that the prevalence of lactose malabsorption did not differ between IBS patients and general population.

Fructans and Galactans

The naturally occurring oligosaccharides are primarily found in commonly ingested plants. Although wheat and onions have low quantities of fructans, but they are important staples of our modern diet and consumed in large amounts. Legumes, lentils, and beans are rich sources of galactans (Table 1). The human gut does not have hydrolases for these oligosaccharides. Hence, they reach the colon where they are fermented into gas and short-chain fatty acids. Butyrate is one of the short-chain fatty acids that is considered to be beneficial for the health of intestinal mucosa and possible protection against colon cancer [28–30]. They also have prebiotic activity because they cause growth of beneficial colonic bacteria mainly *Lactobacilli* and *Bifidobacteria* [31].

Polyols

Sugar alcohols in our diet such as sorbitol, mannitol, lactitol, etc. constitute the polyols, which can only cross the epithelial barrier of the gut through passive diffusion, which is dependent upon molecular size and positioning of hydroxyl groups. Natural sources include fruits like apples, pears, and peaches for sorbitol and vegetables like cauliflower and mushrooms for mannitol. Polyols are increasingly added to our modern diet in the form of sugar substitutes. They not only exert an osmotic effect in small intestine but are also fermented in the colon.

FODMAP Ingestion and Gastrointestinal Symptoms

At least three different mechanisms may contribute to symptoms when patients or volunteers ingest FODMAPs. The limited absorption and chemical breakdown into smaller molecules through fermentation increase the osmotic load in the colon. Gas generated during the fermentation process adds to the colonic filling, which may cause bloating and distension. Luminal filling activates colonic motility, which may accelerate transit and contribute diarrhea or subjectively perceived spasms [32]. Using breath testing, several studies examined the effect of FODMAP intake in healthy volunteers and IBS patients. Ong et al. [33] showed in a randomized, crossover trial that high-FODMAP diet was associated with increased luminal hydrogen production in both IBS patients as well as healthy controls. While methane production did not differ between the two groups, healthy controls switched from methane to hydrogen production during the high-FODMAP diet. This result highlights the interaction between fermentable substances and the gut flora, suggesting that the increase load affects the function of methogenic bacteria, perhaps due to the more acidic environment caused by short-chain fatty acids. Murray et al. [34] also confirmed the findings of increased hydrogen production in a randomized, crossover trial involving healthy volunteers. Breath hydrogen was significantly elevated after ingestion of 40 g fructan solution as compared to 40 g fructose, which correlated with increased colonic gas volumes as compared to glucose (Table 2).

The second and related mechanism is the increase in osmolytes with resulting changes in luminal water content. Using ileostomy output as primary endpoint, a FODMAP-rich diet led to higher effluent weight and water content [35]. Similar changes in intestinal fluid content were subsequently obtained in healthy people using MRI to evaluate small bowel water content [34, 36].

Consistent with the effect of luminal distension on gut motility, Madsen et al. [37] described accelerated small intestinal transit in 11 healthy volunteers after ingestion of a mixture of fructose and sorbitol in comparison with glucose. While these physiological effects similarly affect healthy controls and IBS patients, altered sensory processing or health-related concerns may trigger different responses in these groups. This conceptual model is certainly backed by studies on visceral sensory mechanisms in IBS [38, 39], but still lack empirical support.

Low-FODMAP Diet in IBS

Within the last 7 years, a number of studies have evaluated the clinical efficacy of low-FODMAP diet on IBS patients (Table 2). Shepard et al. [40] first retrospectively analyzed the effect of low-FODMAP diet on 62 IBS patients with 85 % patients reporting improvement on the diet. Another retrospective study [41] compared the effect of dietary advice on low FODMAP with IBS patients who had not received any dietary advice and 35 healthy controls. Patients who had received dietary advice reported reduction in abdominal pain and a better quality of life as compared to patients who had not received dietary advice.

Two prospective, but uncontrolled observational studies [42, 43] diet reported considerable improvement of IBS symptoms on low FODMAP. However, these studies were limited by low completion rates (37–46 %), therefore reducing generalizability of results and there was a potential for placebo effect due to non-blinding. Another recent observational study [44] including 19 IBS patients

Table 2 Studies highlighting the mechanism of symptom induction by FODMAPs and efficacy of low-FODMAP diet

References	Study design	Subjects	Methodology	Evaluation	Results
[40][b]	Retrospective, uncontrolled	IBS with fructose malabsorption ($n = 62$)	Patients were instructed in a diet low in fructose and fructans	Telephone questionnaire utilizing unvalidated symptom scoring tool (−10 to +10)	85 % of compliant patients had symptom improvement
[45][b]	Randomized, double-blinded, placebo-controlled	IBS with fructose malabsorption ($n = 25$)	Patients had previously responded on low-FODMAP diet. They were re-challenged with a diet rich in fructose, fructans, fructose + fructans, and glucose (placebo)	Unvalidated symptom scoring tool (VAS 100 mm)	70 % with fructose, 77 % with fructans, 79 % with fructose + fructans and 14 % with glucose reported symptom worsening ($p < 0.002$)
[33][a,b]	Randomized, controlled, single-blind, crossover	IBS ($n = 15$) Healthy ($n = 15$)	High-FODMAP diet for 2 days Low-FODMAP diet for 2 days	Unvalidated symptom scoring tool (0–3) Hourly H2 profile on second day of each diet	Median symptom score was lower on low-FODMAP diet as compared to high-FODMAP diet in IBS patients Higher H2 production in high versus low-FODMAP diet in IBS patients (242 vs 62 ppm; $p < 0.001$) and also in controls (181 vs 43 ppm; $p < 0.001$)
[35][a]	Randomized, single-blind crossover	Ileostomates without active small bowel disease ($n = 12$)	High-FODMAP diet for 4 days Low-FODMAP diet for 4 days	Measured effluent weigh and water content	Effluent weight on high versus low-FODMAP diet (504 vs 409 g; $p = 0.01$) Effluent water content 20 % increased on high FODMAP ($p = 0.013$)
[36][a]	Randomized, single-blind crossover	Healthy ($n = 11$)	17.5 g mannitol solution 17.5 g glucose solution	Small bowel water content using MRI	Higher small bowel water content after mannitol versus glucose (381 vs 47 ml; $p < 0.001$)
[56][b]	Non-randomized, controlled	IBS ($n = 82$)	Low-FODMAP dietary advice (43 patients) Standard dietary advice (39 patients)	Unvalidated questionnaire utilizing 7 point scale	76 versus 54 % patients in low-FODMAP versus control group were satisfied with symptom control 86 versus 49 % patients in low-FODMAP versus control group had improvement with composite symptom score
[46][b]	Randomized, controlled	IBS ($n = 41$)	Low-FODMAP dietary advice (22 patients) Habitual diet (19 patients)	GI symptom rating scale Adequate relief question Bristol stool form scale	68 versus 23 % patients reported adequate relief on low-FODMAP diet versus habitual diet ($p = 0.005$)
[41][b]	Retrospective, case–control	IBS ($n = 79$) Healthy ($n = 35$)	Guided advice (43 patients) Unguided advice (36 patients)	Birmingham IBS symptom score IBS QoL	65 % patients completed the study. Reduction in abdominal pain in guided versus unguided Marked improvement in QoL in guided versus unguided
[42][b]	Prospective, uncontrolled	IBS ($n = 192$)	Dietary advice on low-FODMAP diet	GI symptom rating scale	Only 47 % (90 patients) completed the study Abdominal pain, bloating, flatulence and diarrhea improved significantly ($p < 0.001$) 72 % were satisfied with symptom control
[43][b]	Prospective, uncontrolled	IBS ($n = 46$)	Three 45-min dietary sessions given on low-FODMAP diet	Birmingham IBS symptom score IBS QoL	Only 37 % patients completed the study. Marked improvement in QoL and overall symptoms

Table 2 continued

References	Study design	Subjects	Methodology	Evaluation	Results
[34][a]	Randomized, single-blind, crossover	Healthy ($n = 17$)	Three different solutions containing 40 g of fructose, glucose, or fructan One solution containing 40 g each of fructose and glucose	Small bowel water content using MRI	Higher small bowel water content after fructose (area under curve = 67 L/min) versus glucose (36 L/min). Reduced to (46 L/min) with fructose and glucose Fructan only increased colonic H2 production
[47][b]	Randomized, controlled, single-blind, crossover	IBS ($n = 30$) Healthy ($n = 8$)	Low-FODMAP diet versus typical Australian diet for 21 days each	Unvalidated symptom scoring tool (VAS 100 mm) Stool frequency Stool water content	IBS patients had lower overall symptoms on low-FODMAP diet (23 mm) versus Australian diet (45 mm) $p < 0.001$
[44][b]	Prospective, uncontrolled	IBS ($n = 19$) IBS-D = 8 IBS-C = 4 IBS-M = 7	Dietary advice given to patients on low-FODMAP diet. This diet was continued for 6 weeks	IBS-Severity Scoring System 5 symptoms evaluated on VAS 100 mm each IBS QoL 34 item validated questionnaire (score 1–5)	On low-FODMAP diet, IBS–SSS median score was 151 versus 278 on habitual diet ($p < 0.01$) On low-FODMAP diet IBS QoL median 67 versus 81 on habitual diet ($p < 0.01$)
[53]	Randomized, controlled, single-blind, crossover	IBS ($n = 27$) Healthy ($n = 6$)	Low-FODMAP diet versus typical Australian diet for 21 days each	Fecal indices including pH, short-chain fatty acids, bacterial abundance and diversity	Low-FODMAP diet had higher pH, similar short-chain fatty acids, greater microbial diversity, and reduced total bacterial abundance as compared to Australian diet

[a] Studies describing the mechanism of symptom induction by FODMAPs in diet

[b] Studies evaluating symptomatic improvement after low-FODMAP diet

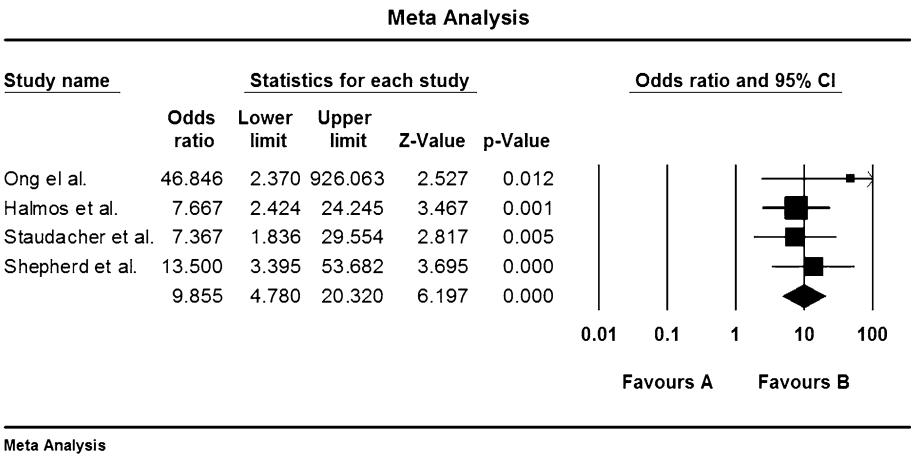

Fig. 1 Meta-analysis of randomized control trials showing the effectiveness of low-FODMAP diet in patients with IBS

on a low-FODMAP diet for 6 weeks also showed significant improvement in symptoms and quality of life.

To date, five randomized, controlled trials (Table 2) have been conducted on low-FODMAP diet. The trials differed in approach, duration, and endpoints. Despite these shortcomings, we used the dichotomized response rate to estimate the overall impact of this dietary approach on IBS symptoms (Fig. 1). Four of the investigations evaluated efficacy of diet, and one focused on the effect of gut microbiota. Shepherd et al. [45] reported their findings on 25 IBS patients who had been on low-FODMAP diet for a median of 24 months after re-challenging them with certain FODMAPs. As compared to 14 % on glucose (placebo), 70, 77, and 79 % reported worsening on fructose, fructans, and a mixture of fructose and fructans, respectively. Ong et al. [33] chose a different approach by comparing the effects of low-FODMAP (9 g/day) versus high-FODMAP (50 g/day) diets on 15 IBS patients and 15 healthy subjects. Median symptom scores were significantly improved in IBS patients on low-FODMAP diet. While encouraging, the short trial duration of only 2 days limits our ability to predict the more lasting effects required to truly improve a chronic problem, such as IBS. In another trial, 22 IBS patients received dietary advice on low-FODMAP diet and 19 IBS patients received dietary advice on habitual diet. As compared to 23 % patients following habitual diet [46], 68 % patients in low-FODMAP group reported adequate symptom control. The initial reports of impressive benefit were also supported by the recent single-blinded RCT, which compared the efficacy of low-FODMAP diet with typical Australian diet and showed improvement in overall symptoms in 70 % of IBS patients on low-FODMAP diet [47]. As shown in Fig. 1, the results consistently support the utility of this relatively simple and safe dietary intervention with an estimated number needed to treat (NNT) of 2.2 (95 % confidence interval: 1.89–2.51).

A subset of IBS patients can have non-celiac gluten sensitivity and follow a gluten-free diet. Whether avoidance of gluten or FODMAPs is the source of symptomatic relief is a debatable topic because wheat is a rich source of both gluten and fructans. Two studies with conflicting results shed light on this topic. The first trial involved 34 patients of non-celiac gluten intolerance with adequate symptom control on a gluten-free diet [48]. They compared the effect of gluten versus placebo in the generation of symptoms. As compared to 40 % in the placebo group, 68 % reported worsening of symptoms in the gluten group. A subsequent study [49] failed to show that gluten induced symptoms in patients with non-celiac gluten sensitivity. This study however demonstrated that all patients had better symptom control on low-FODMAP diet. While the limited data do not allow firm conclusions, these results suggest that the more restrictive approach with significant reduction of fermentable substances may be more effective than the isolated exclusion of gluten dietary management of IBS patients.

Low-FODMAP Diet and Gut Microbiota

Restricting fermentable materials in the diet will definitely affect the microbial flora within the colon [50–52]. Staudacher et al. [46] studied the effect of low-FODMAP diet on gut microbiota and found that it was associated with significant reduction in bifidobacteria. Interestingly, there was no change in fecal short-chain fatty acids. Halmos et al. [53] recently reported a detailed analysis of shifts in gut flora during the FODMAP diet. As one might expect, there was a lower absolute abundance of total bacteria with a decline in butyrate-producing bacteria and several organisms with potential prebiotic properties (e.g., *A. muciniphila*, *R. gnavus*). Relative abundance of Clostridium cluster XIVa was decreased in low-FODMAP diet as

compared to Australian diet. However, this study did not reveal a lower relative abundance of bifidobacteria with interventional diet as shown by Staudacher et al. [46]. As the impact of dietary changes was assessed after 7–21 days, it remains to be seen whether prolonged dietary changes will result in additional alteration of the microbial colonization.

A Practical Dietary Approach

Dietary modifications always played a role in the management of IBS. However, decisions related to food intake and/or avoidance were often based on subjective intolerance and frequently required time-consuming analyses of food diaries to identify potential trigger food. The initial data indicate that the FODMAP diet is not only based on a conceptual model that may be more broadly applicable rather than focusing on potential idiosyncrasies, but also seems to have an impressive response in the first clinical trials with NNT that compare favorably with medical and psychologically oriented treatment approaches [54]. While additional studies are still needed to better define the role of this dietary approach, the safety profile and low cost compared to more traditional approaches should prompt healthcare providers to shift their clinical practice, focusing more on education and integrating dietary choices as an integral component of the multifaceted management strategy for IBS.

If the manipulation dietary habits indeed play an increasingly important role in management strategies of IBS, then more than confirmatory trials on the long-term efficacy of FODMAP exclusion or other approaches on IBS symptoms are needed. In trials and clinical settings, a review of dietary habits may enable healthcare providers to select patients more likely to respond to such therapies. Understanding the rationale and applying the principle of the FODMAP or other diets requires active patient involvement and education. The integration of patient education into treatments has become an integral part of diabetes therapy. Resources ranging from books to digital media or dieticians are widely available, but will need to be evaluated to determine the most effective and cost-effective approach. Lastly, we will need to see whether the impressive short-term results shown in recent studies will indeed be maintained over longer periods of time and will not be associated with the development of nutritional deficiencies.

Despite these open and important questions, physicians should integrate dietary histories into their assessment of patients. Based on the current evidence, IBS patients should be informed about the impressive potential of the FODMAP diet. Dieticians traditionally play an important role in educating patients about dietary treatments and should thus focus on the various low-FODMAP food sources when dealing with IBS patients (Table 3). With the widespread use of digital devices, combining such conventional strategies with modern information technology may reduce cost, improve understanding, and enhance adherence.

While some of the trials indicate that a shorter duration may suffice, dietary changes should be implemented for 2–6 weeks before concluding about the overall impact on symptom severity. Therefore, follow-up appointments with dietician are necessary. If patients report improvement, dietary re-challenge with FODMAPs may be tried gradually. This method may not only determine thresholds for symptom occurrence, but can obviously liberalize the diet and thus increase and simplify food choices for the affected persons. However, if the patients report lack of symptom control with dietary intervention, the first step is to evaluate compliance with the diet, followed by search for confounding variables like food chemicals, food colors, and fermentable fibers notorious to cause symptoms and excluding them from diet. This process will definitely require motivation on the part of the patient, dietician, and physician. Despite aggressive dietary interventions, there would be approximately 20–25 % patients who might not respond at all [55].

Table 3 Alternative low FODMAPs food sources

Fruits	Bananas, berries, cantaloupe, grapes, grapefruit, honeydew, kiwi, kumquat, lemon, lime, mandarin, orange, passion fruit, pineapple, rhubarb, tangerine
Vegetables	Bamboo shoots, bell peppers, cucumbers, carrots, celery, corn, eggplant, lettuce, pumpkin, potatoes, yams, tomatoes, zucchini
Dairy	Lactose-free dairy, hard cheeses (cheddar, colby, parmesan, swiss), mozzarella, sherbet, almond milk, rice milk, rice milk ice cream
Grains	Wheat-free grains/wheat-free flours (gluten-free grains are wheat free): bagels, breads, hot/cold cereals (corn flakes, cheerios, cream of rice, grits, oats, etc.), crackers, noodles, pastas, quinoa, pancakes, pretzels, rice, tapioca, tortillas, waffles
Proteins	Beef, chicken, canned tuna, eggs, egg whites, fish, lamb, pork, shellfish, turkey
Sweeteners	Maple syrup, golden syrup, glucose

Conclusion

Patients with IBS commonly identify food as a symptom trigger. The FODMAP diet provides a conceptual framework that integrates our understanding of gastrointestinal physiology with the emerging findings of reciprocal interactions between luminal contents, the microbial

colonization of the gut and its function. The available data are impressive and should prompt healthcare providers to include the FODMAP diet into their repertoire of treatment options. Thus, the FODMAP diet is ready for use. Before calling this or other dietary approaches as being "ready for prime time," we need to better understand long-term effects and side-effects, compare its efficacy and its cost to alternative management strategies, and study how to best teach, implement, and reinforce such therapies.

Conflict of interest All authors have no financial disclosures or conflicts of interest to declare.

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