

The low FODMAP diet improves gastrointestinal symptoms in patients with irritable bowel syndrome: a prospective study

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SUMMARY

Background and aim: Current treatment for irritable bowel syndrome (IBS) is suboptimal. Fermentable oligo-, di-, mono-saccharides and polyols (FODMAPs) may trigger gastrointestinal symptoms in IBS patients. Our aim was to determine whether a low FODMAP diet improves symptoms in IBS patients. **Methods:** Irritable bowel syndrome patients, who had performed hydrogen/methane breath testing for fructose and lactose malabsorption and had received dietary advice regarding the low FODMAP diet, were included. The effect of low FODMAP diet was prospectively evaluated using a symptom questionnaire. Furthermore, questions about adherence and satisfaction with symptom improvement, dietary advice and diet were assessed. **Results:** Ninety patients with a mean follow up of 15.7 months were studied. Most symptoms including abdominal pain, bloating, flatulence and diarrhoea significantly improved ($p < 0.001$ for all). 75.6%, 37.8% and 13.3% of patients had fructose, lactose malabsorption or small intestinal bacterial overgrowth respectively. Fructose malabsorption was significantly associated with symptom improvement (abdominal pain odds ratio (OR) 7.09 [95% confidence interval (CI) 2.01–25.0], bloating OR 8.71 (95% CI 2.76–27.5), flatulence OR 7.64 (95% CI 2.53–23.0) and diarrhoea OR 3.39 (95% CI 1.17–9.78), $p < 0.029$ for all). Most patients (75.6%) were adherent to the diet, which was associated with symptom improvement (abdominal pain, bloating, flatulence and diarrhoea all significantly associated with adherence, $r > 0.27$, $p < 0.011$). Most patients (72.1%) were satisfied with their symptoms. **Conclusions:** The low FODMAP diet shows efficacy for IBS patients. The current strategy of breath testing and dietary advice provides a good basis to understand and adhere to the diet.

What's known

- The low FODMAP diet has been associated with an improvement of symptoms in retrospective observational and a randomised intervention clinical study.
- Hydrogen and methane breath tests predict lactose and fructose malabsorption.

What's new

- This is the first prospective study to confirm the efficacy of the low FODMAP diet for patients with IBS.
- IBS Patients who are fructose malabsorbers are more likely to respond to a low FODMAP diet.

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Disclosures

The authors declare that they have no conflict of interest.

Introduction

Irritable bowel syndrome (IBS) is a common gastrointestinal (GI) disorder, in which abdominal pain is associated with defecation or a change in bowel habit (1,2). Common IBS symptoms include abdominal pain, bloating, constipation and/or diarrhoea (3). Ten to 20% of the adult population suffers from IBS, which is twice as frequent among females (2–5.) IBS is associated with a significant decrease in quality of life and places a major economic burden on patients, healthcare systems and the wider community. Although IBS is common, its cause remains poorly understood (1) and IBS treatment is focused on reducing symptoms. Treatments for IBS include pharmaceuticals, psychological therapy, fibre, probi-

otics, lifestyle and dietary modifications. However, the current treatment of IBS is often suboptimal and effective treatments are desperately needed (2,5–9). The relationship between diet and abdominal symptoms is well recognised (1,10–12) and many dietary components (e.g. gluten, fat, dairy, coffee or alcohol) may elicit GI symptoms (10,11,13). FODMAPs (Fermentable Oligo-, Di- and Mono-saccharides And Polyols) are short-chain carbohydrates, which are poorly absorbed in the small intestine, are highly fermentable, increasing the osmotic load in the intestine. The increased delivery of water to, and the production of gas in, the colon causes increased luminal distention (14,15) leading to symptoms, often mediated by visceral hypersensitivity (16,17). Furthermore, FODMAPs may induce altered motility,

bloating, pain/discomfort and wind (7,15,18). A range of retrospective and one rechallenge study has shown that a low FODMAP diet for IBS patients leads to a significant reduction in GI symptoms (7,14,18–20). However, prospective observational studies have not been performed assessing the efficacy of a low FODMAP diet, informed by hydrogen breath test results for fructose and lactose malabsorption, in patients with IBS. We aimed to determine prospectively whether a low FODMAP diet leads to improved symptoms in IBS patients.

Methods

Patients

This study was a prospective observational study of IBS patients who were referred for hydrogen/methane breath testing for fructose and lactose malabsorption and dietary consultation with experienced dietitians. Over the last 3 years, 192 IBS patients had performed breath tests, received dietary intervention and completed a symptom questionnaire. Patients were excluded from the study if they had significant GI comorbidities, such as inflammatory bowel disease, coeliac disease, significant diverticular disease or a past history of bowel resection. All patients had been assessed by either a Gastroenterologist or Colorectal Surgeon prior to referral and most had undergone colonoscopy and other appropriate investigations. No alteration was made to the patients' medical therapy during the study period, although probiotics were ceased before the breath testing if a patient had been taking these.

Breath testing

The hydrogen/methane breath testing was performed on three separate days for lactulose [for small intestinal bacterial overgrowth (SIBO)], fructose and lactose. Patients followed a low FODMAP and fibre diet for 24 h, and avoided vitamins, minerals, laxatives, antilaxatives and fish-oil capsules. Participants also abstained from antibiotics or probiotics 2 weeks prior to testing. Patients fasted from 10 pm the night before the test.

The breath tests were performed using a Bedfont-gastrolyser (Kent, United Kingdom) for breath hydrogen measurement and/or a Quintron microlyser (Wisconsin, United States of America) for breath methane. Lactulose 10 ml was given on the first day to confirm hydrogen or methane production and to diagnose SIBO. SIBO was diagnosed if there was a significant rise in breath hydrogen (greater than 10 ppm on two consecutive readings) above baseline within 60 min of lactulose ingestion. Breath tests were performed every 15 min until a positive test

was encountered or until 3 h had passed. Fructose (35 g dissolved in water) and lactose (50 g dissolved in water) tests were performed on the second and third day. The thresholds for a positive were the same as those for lactulose (21). The results of all the breath tests were reported by a single Gastroenterologist (RBG).

Dietary advice

The consultations were performed by three dietitians. Each had been trained by expert dietitians who had been involved in the formulation and clinical implementation of the low FODMAP diet. The dietitian consultation comprised an initial 1-h appointment and a 30-min follow up 6 weeks later. All patients completed a 6-day food record prior to the consultation. During the first consultation, the food record was carefully reviewed and the principles of the low FODMAP diet were explained. Food lists of safe and restricted foods were used to develop a diet plan, individualised for each person using information extracted from the food record and breath testing results. Adequate intake of fibre and calcium was ensured. Written information on safe and eliminated foods, a shopping guide based on products low in FODMAPs and information concerning places to buy specific foods, was given. The dietitians also gave advice on how to cook without onion and garlic, and recipes were provided if needed. Patients could contact the dietitians during the elimination diet for further information.

After 6 weeks, a 30-min follow-up consultation was scheduled to review symptoms and progress. Patients were provided with written information concerning the limited reintroduction of restricted group of carbohydrates.

Patient assessments

In addition to the baseline symptom diaries using the GI symptom rating scale (22,23), patients were either contacted by email or post for a follow-up assessment of the safety and efficacy of the diet. This occurred in early 2012 and was independent of the 6-week follow-up consultation. Both questionnaires contained 20 questions about bowel habits with patients rating their symptom intensity on a seven-point Likert scale. The same questions were asked at baseline and at follow up. The follow-up questionnaire also explored adherence and opinions about the diet. In addition, patients evaluated their degree of symptom change retrospectively (bloating, abdominal pain/discomfort, flatulence/wind, diarrhoea, constipation, nausea and energy levels) using a seven-point Likert scale used by other investigators (18). To evaluate the adherence to the diet, questions

included taste, price, satisfaction, dietary advice, breath tests and the ease of the diet (18,19,24). Participation was voluntary, and the data were confidential and reported anonymously. It was clearly explained to participants that the responses returned either on line or by mail were to be collated and analysed by a researcher who was not a member of the clinical team and that all responses would be confidential. Participants were encouraged to answer the questions honestly. The study fulfilled the local ethics committee's definition of audit activity.

Statistical analysis

Statistical analysis was performed using SPSS Statistics 17.0 (SPSS Inc, Chicago, IL, USA). Baseline descriptive data and comparison between the questionnaire responders and the non-responders were analysed using chi-squared and independent *t*-tests. Baseline symptoms were divided into symptoms absent (no problem at all), mild (minor, mild or moderate problem) and severe (moderate–severe, severe or very severe problem). The symptoms were compared using the Mann–Whitney *U*-test. To compare the initial symptom score with the follow-up symptom score, we used the Wilcoxon signed-rank test. As previously described, we dichotomised symptom change scores into improved vs. not improved (18). Further analyses were performed to determine whether there was an association between symptom improvement (dichotomous) and the outcome of the breath tests,

resulting in odds ratios with 95% confidence intervals. Likewise, we dichotomised adherence (19) and opinions about the diet/dietary advice. To describe the correlation between adherence and symptom change, a Spearman's rank order test was performed, using the un-dichotomised scores. A *p*-value ≤ 0.05 was considered to be statistically significant.

Results

Ninety (46.9%) of 192 patients with IBS, who had received dietary intervention and had performed hydrogen breath tests, completed the follow-up questionnaire. We describe the symptom change in these 90 patients, with a mean follow up of 15.7 (± 9.0) months. The characteristics of the patient groups are described in Table 1.

There were no significant differences between the responders and the non-responders with regard to age, outcome of the hydrogen breath tests and the presenting symptoms. However, more women replied to the invitation to take part in the study than men (female responders 84.4%, non-responders 64.7%, *p* = 0.003). Sixty-eight (75.6%), 34 (37.9%) and 12 (13.3%) patients had fructose, lactose malabsorption and SIBO respectively.

Improvement of symptoms

There was a significant positive change in almost all of the reported symptoms between baseline and

Table 1 Characteristics of the study population comparing those who replied to the follow-up survey and those who did not reply

Characteristics	Responders, n = 90			Non-responders, n = 102			p
Female, n (%)	76 (84.4)			66 (64.7)			.003*
Age(years), mean (SD)	47.0 (15.3)			43.0 (14.6)			.069**
Follow-up time(months), mean (SD)	15.7 (9.0)			—			
Appointments dietitian n (%)				—			
1	22 (24.4)						
2	53 (58.9)						
≥ 3	15 (16.7)						
Breath tests n (%)							
Positive fructose	68 (75.6)			77 (75.5)			1.00*
Positive lactose	34 (37.8)			27 (26.5)			.120*
Positive SIBO	12 (13.3)			11 (10.8)			.659*
Baseline symptoms	Absent n (%)	Mild n (%)	Severe n (%)	Absent n (%)	Mild n (%)	Severe n (%)	
Bloating (n = 192)	15 (16.9)	41 (46.1)	31 (37.1)	15 (14.7)	58 (56.9)	29 (28.4)	.443***
Abdominal pain (n = 152)	9 (12.5)	42 (58.3)	21 (29.2)	9 (11.3)	52 (65.0)	19 (23.8)	.635***
Passing gas (n = 192)	14 (15.6)	43 (47.8)	33 (36.7)	14 (13.7)	55 (53.9)	33 (32.4)	.744***
Diarrhoea (n = 189)	41 (46.6)	31 (35.2)	16 (18.2)	40 (39.4)	35 (34.7)	26 (25.7)	.215***
Constipation (n = 190)	37 (41.6)	37 (41.6)	15 (16.9)	46 (45.5)	38 (37.6)	17 (16.8)	.669***
Nausea (n = 189)	38 (42.7)	37 (41.6)	14 (15.7)	44 (44.0)	37 (37.0)	19 (19.0)	.921***

*Chi-squared test, **t-test, ***Mann–Whitney U-test.

follow up (Table 2). 'Feeling full even long after stopping eating' ($p = 0.051$), 'burping' ($p = 0.275$) and 'passage of mucus' ($p = 0.890$) did not improve significantly. To determine if the results of dietary intervention could be explained purely on the basis of the characteristics of those who replied to the questionnaire, we repeated the analysis including non-repliers, assuming that none of them had improved with the intervention (i.e. they were assigned the same follow-up symptom scores as their baseline assessment). Table 2 shows that the same symptoms remain significant across the whole cohort.

Table 3 shows the degree of improvement for each symptom as a function of the absolute difference in scores along the Likert scale used for each symptom (as opposed to Table 2, which only shows whether or not there has been an improvement). Not only did most patients' symptoms improve but also the magnitude of the improvement was usually significant (Table 3).

Although the patients completed the baseline and follow-up symptom questionnaire independently, we were also interested whether each patient thought that symptoms had improved on the diet (using questionnaires utilised by other investigators who had assessed the low FODMAP diet retrospectively) (18). Figure 1 shows that the majority report an improvement on the symptoms assessed.

Associations with symptom change

Patients with fructose malabsorption were significantly more likely to report an improvement in bloating, abdominal pain/discomfort, flatulence/wind, diarrhoea and constipation following dietary intervention than those without breath test evidence of fructose malabsorption (Table 4). For most symptoms, there were no demographic differences between non-responders and responders except for abdominal pain, where male patients were less likely than female patients to improve ($p = 0.015$).

Table 2 Symptom severity scores at baseline and follow up using the gastrointestinal symptom rating scale (mean follow up 15.7 months)

Bowel symptom	n	Baseline median (25–75%)	n	Follow-up median (25–75%)	p (two-tailed)*	p (two-tailed) assuming non-repliers did not change symptoms**
Abdominal pain	72	4 (2–5)	90	2 (1–3)	.000	.000
Bloating	89	4 (2–5)	90	2 (1–4)	.000	.000
Constipation	89	2 (1–4)	90	1 (1–2)	.003	.002
Diarrhoea	88	2 (1–4)	90	1 (1–2)	.000	.000
Nausea	89	2 (1–3)	90	1 (1–2)	.000	.000
Passing gas	90	4 (2–5)	90	2 (2–4)	.000	.000
Burping	89	2 (1–3)	90	1 (1–3)	.275	.308
Loose bowel movements	88	3 (1–4)	90	2 (1–3)	.000	.000
Hard stools	88	1 (1–3)	90	1 (1–2)	.001	.000
Urgent need for bowel movement	90	3 (1–5)	90	2 (1–3)	.000	.000
Feeling not completely emptied after bowel movement	90	3 (2–5)	90	2 (1–3)	.000	.000
< 3 bowel movements a week	88	1 (1–1)	90	1 (1–1)	.015	.015
> 3 bowel movements a day	90	2 (1–4)	90	1 (1–2)	.000	.000
Straining during a bowel movement	88	2 (1–4)	90	1 (1–2)	.000	.000
Abdominal pain/discomfort relieved by bowel movement	90	4 (2–5)	90	2 (1–3)	.000	.000
Feeling full shortly after having started a meal	88	2 (1–4)	90	1 (1–2)	.001	.000
Feeling full even long after you stopped eating	90	1 (1–4)	90	1 (1–2)	.051	.051
Visible swelling abdomen	89	3 (1–5)	90	2 (1–3)	.000	.000
Passage of mucus	89	1 (1–1)	90	1 (1–2)	.890	.890
Indigestion	88	1.5 (1–3)	90	1 (1–2)	.015	.015

*Wilcoxon signed-rank test performed on the baseline and follow-up scores of repliers.

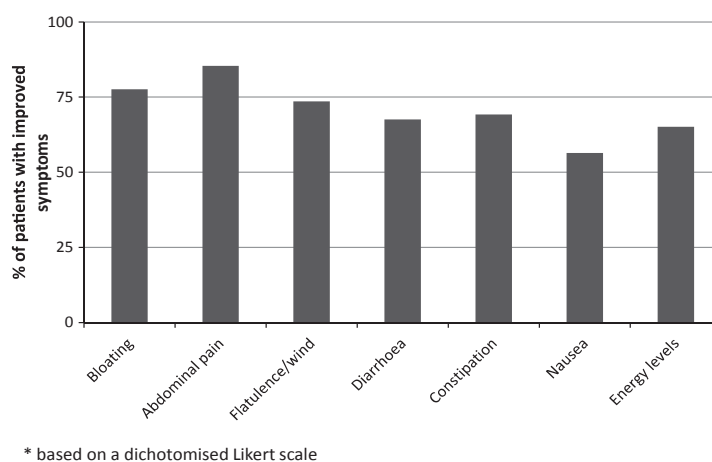
**Wilcoxon signed-rank test performed on all patients, assuming that the non-repliers had no improvement in Likert scale from baseline.

Higher symptom scores reflect more severe symptoms.

Table 3 The degree of improvement for each symptom using Likert scale symptom scores

Bowel symptom	n	Symptom never experienced n (%)	Improvement n (%)*					2 scales or greater improvement
			No change/worsening symptoms	1 scale	2 scales	3 scales	4–6 scales	
Abdominal pain	72	9 (12.5)	18 (28.6)	17 (27.0)	15 (23.8)	7 (11.1)	6 (9.5)	28 (44.4)
Bloating	89	15 (16.9)	21 (28.4)	25 (33.8)	14 (18.9)	6 (8.1)	8 (10.8)	28 (37.8)
Constipation	89	37 (41.6)	18 (34.6)	14 (26.9)	10 (19.2)	5 (9.6)	5 (9.6)	20 (38.5)
Diarrhoea	88	41 (46.6)	9 (23.4)	8 (17.0)	12 (25.5)	6 (12.8)	10 (21.3)	28 (59.6)
Nausea	89	38 (42.7)	11 (21.6)	14 (27.5)	13 (25.5)	6 (11.8)	7 (13.7)	26 (51.0)
Passing gas	90	14 (15.6)	29 (38.2)	14 (18.4)	16 (21.1)	11 (14.5)	6 (7.9)	33 (43.4)
Burping	89	41 (46.1)	23 (47.9)	11 (22.9)	5 (10.4)	5 (10.4)	4 (8.3)	14 (29.1)
Loose bowel movements	88	30 (34.1)	16 (27.6)	11 (19.0)	13 (22.4)	14 (24.1)	4 (6.9)	31 (53.4)
Hard stools	88	46 (52.3)	9 (21.4)	11 (26.2)	13 (31.0)	5 (11.9)	4 (9.5)	22 (52.4)
Urgent need for bowel movement	90	30 (33.3)	16 (26.7)	10 (16.7)	15 (25.0)	6 (10.0)	13 (21.7)	34 (56.7)
Feeling not completely emptied after bowel movement	90	19 (21.1)	25 (35.2)	19 (26.8)	9 (12.7)	10 (14.1)	8 (11.3)	27 (38.0)
< 3 bowel movements a week	88	67 (76.1)	7 (33.3)	5 (23.8)	4 (19.0)	3 (14.3)	2 (9.5)	9 (42.3)
> 3 bowel movements a day	90	43 (47.8)	7 (14.9)	12 (25.5)	14 (29.8)	6 (12.8)	8 (17.0)	28 (59.6)
Straining during a bowel movement	87	38 (43.7)	13 (26.5)	12 (24.5)	18 (36.7)	2 (4.1)	4 (8.2)	24 (49.0)
Abdominal pain/discomfort relieved by bowel movement	90	16 (17.8)	18 (24.3)	13 (17.6)	19 (25.7)	17 (23.0)	7 (9.5)	43 (58.1)
Feeling full shortly after having started a meal	89	39 (43.8)	11 (22.0)	22 (44.0)	8 (16.0)	5 (10)	4 (8.0)	17 (34.0)
Feeling full even long after you stopped eating	90	46 (51.1)	13 (29.5)	15 (34.1)	7 (15.9)	7 (15.9)	2 (4.5)	16 (36.4)
Visible swelling abdomen	89	31 (34.8)	20 (34.5)	10 (17.2)	11 (19.0)	8 (13.8)	9 (15.5)	28 (48.3)
Passage of mucus	89	70 (78.7)	8 (42.1)	1 (5.3)	5 (26.3)	1 (5.3)	4 (21.1)	10 (52.6)
Indigestion	88	44 (50.0)	12 (27.3)	19 (43.2)	8 (18.2)	4 (9.1)	1 (2.3)	13 (29.5)

*Patients who did not have the symptom at baseline have not been included in the denominator for % improvement.

**Figure 1** Percentage of patients that report self-experienced improvement (based on a dichotomised Likert scale)

Adherence to the diet

Most patients described ongoing adherence to the diet ($n = 68$, 75.6%). Describing those most to least

adherent, 32 (35.6%) patients followed the diet as taught at all times except on some occasions; 11 (12.2%) followed the diet at all times; 12 (13.3%)

Table 4 Association between fructose malabsorption and symptom improvement

Symptom (n)	Improved with FM N (%)*	Improved without FM N (%)*	OR (95% CI)	p (Fisher exact test)
Bloating (85)	57 (67.1)	9 (10.6)	8.71 (2.76–27.5)	.000
Abdominal pain/discomfort (89)	62 (69.7)	14 (15.7)	7.09 (2.01–25.0)	.002
Flatulence/wind (88)	56 (63.6)	8 (9.1)	7.64 (2.53–23.0)	.000
Diarrhoea (75)	40 (54.1)	10 (13.5)	3.39 (1.17–9.78)	.029
Constipation (66)	37 (56.9)	8 (12.3)	3.78 (1.18–12.1)	.032

*Percentages are calculated using the number of participants who experienced each symptom as the denominator (shown in brackets in the first column). Results are expressed as odds ratios (OR) and 95% confidence intervals (CI). FM, fructose malabsorption.

patients also at all times except when eating away from home; 13 (14.4%) of the patients consider themselves as being adherent to the diet for at least 50% of the time; 22 (24.4%) participants were non-adherent; 13 (14.4%) followed the diet for up to 3 months, but not anymore; five (5.6%) followed the diet as taught immediately, but less than 50% of the time now; four (4.4%) never followed the diet.

Adherence and symptom change

There was a significant positive correlation between adherence and improvement in bloating ($r_s(83) = 0.273$, $p = 0.011$), abdominal pain/discomfort ($r_s(87) = 0.271$, $p = 0.010$), flatulence/wind ($r_s(85) = 0.374$, $p = 0.000$), diarrhoea ($r_s(72) = 0.310$, $p = 0.007$), constipation ($r_s(63) = 0.296$, $p = 0.017$) and energy levels ($r_s(81) = 0.271$, $p = 0.013$).

Satisfaction with symptom improvement, dietary advice and diet

At follow up, 62 (72.1%) patients were satisfied with their overall symptoms. In total, 77 (89.5%) thought that the written information was easy to understand, while 66 (75.9%) believed that having had breath testing made the diet easier to understand and adhere to. Fifty-one (60%) patients stated that the diet was easy to follow, 56 (65.1%) could easily find suitable products and 37 (43.5%) were able to incorporate the diet easily into their life. The overall taste was liked by 47 (54.7%) patients, although 21 (24.4%) thought that the diet was too expensive. Sixteen (18.2%) believed that simply being given a list of foods to avoid, it would have been as effective as seeing the dietitian for a consultation while 37 (44.6%) patients would have liked to have seen the dietitian for a further follow-up appointment.

Variables associated with adherence

Patients were asked to rank five variables that were associated with efficacy and adherence to the diet.

Written information (mean rank 1.73 (± 0.76)) and dietitian consultation (1.89 (± 1.09)) were ranked highest while the support of family and friends (3.33 (± 1.15)), low FODMAP cookbooks (3.89 (± 1.00)) and online information (4.11 (± 1.00)) were thought to be less important. The association between adherence to and aspects of the diet was explored. Patients who were most likely to adhere to the diet were those who liked the overall taste of the diet ($p = 0.001$), found the diet easy to follow ($p = 0.004$), found the breath test results helped to understand the role of the diet ($p < 0.001$) and found the diet easy to incorporate into their life ($p = 0.016$). Understanding of written information given to patients about the diet, ease of identifying suitable foods and the expense of the diet were not significantly associated with good or poor adherence to the diet.

Discussion

In this observational study, we have prospectively assessed symptoms in IBS patients who received hydrogen/methane breath testing and dietary advice concerning a low FODMAP diet. Our study confirms that the low FODMAP diet offers symptomatic benefit for IBS patients and leads to a significant improvement for the majority of patients. Diet adherence is crucial to the success of the diet and fructose malabsorption is strongly associated with efficacy. The most common symptoms described at the initial consultation are representative of IBS patients described elsewhere (2,5). Most IBS patients have visceral hypersensitivity and symptoms may be triggered by luminal distension (16,17). A high FODMAP diet has been shown to lead to luminal distension through colonic fermentation and increased delivery of fluid to the colon (14,15).

Previous studies of the effect of low FODMAP diet for IBS patients assessed a smaller range of

symptoms such as bloating, abdominal pain, passing gas, diarrhoea, constipation and nausea (7,18,19). To more fully describe the effects of a low FODMAP, we described a wider range of symptoms. In addition to confirming the beneficial effect of low FODMAP diet on core IBS symptoms, we have shown that related GI symptoms also improve.

While there was a significant improvement in most symptoms, burping, passage of mucus and the feeling of satiety did not improve with the low FODMAP diet. This may be caused by the low frequency of these symptoms in our population but, in addition, one might not expect a significant improvement in these given the proposed mechanism of action for FODMAPs. Our study has also shown consistent results between prospectively collected and the self-reported effects of low FODMAP diet that has been used by other investigators (18). Furthermore, the degree of improvement is comparable with that described by Staudacher et al. demonstrating a consistent effect of the low FODMAP diet between populations.

The observation that constipation also improved on a low FODMAP diet may seem counterintuitive given the proposed mechanism of action for most FODMAPs. However, this may reflect other aspects of dietary advice, which ensure sufficient fibre and other dietary constituents as part of a balanced diet. A key aspect to the dietary advice is ensuring not only that trigger foods are removed but also that the resultant diet is balanced. It is conceivable that this may have led to more fibre in the diet of those who previously had low fibre diets and were constipated.

We have found a high rate of fructose malabsorption (75.6%) compared with others (21), although there is a large variation in fructose malabsorption rates between populations (20,25). The high rate in our population could be attributable to a hospital referral bias because many patients were referred by Gastroenterologists rather than General Practitioners. Furthermore, the cut-off used to define fructose malabsorption is controversial (21,25–27). We used a 10 ppm rise of breath hydrogen on two occasions or else a rise greater than 15 ppm on one occasion that was accompanied by GI symptoms. This definition is on the aggressive side for diagnosing fructose malabsorption, but may be relevant given the strong association with efficacy of the low FODMAP diet. Despite the higher prevalence of fructose malabsorption, the prevalence of lactose malabsorption is comparable to other studies (21).

The need for breath testing to identify individuals with fructose and lactose malabsorption prior to dietary interventions has been debated (12,28,29). Parker et al. suggested that it is unnecessary to

distinguish IBS patients with lactose malabsorption from those without (28). Furthermore, other studies report that there is no difference in the prevalence of SIBO between patients with IBS and healthy volunteers (29). Our study suggests that IBS patients with fructose malabsorption are significantly more likely than those without to respond to the low FODMAP diet. Therefore, we advocate the use of these tests, not only to direct dietary interventions but also to provide prognostic information. While lactose malabsorption and SIBO were less discriminatory, testing may play a specific role in a small number of patients. We hypothesise that the association between fructose malabsorption and efficacy of the diet may reflect large amounts of fructose in the diet of these IBS patients. This would make fructose more amenable to significant dietary reductions than other FODMAPs. Otherwise, this observation may reflect improved adherence among patients with fructose malabsorption. It is possible that a positive breath test result led to improved adherence to the diet, even though this was not shown in our study.

Not surprisingly, adherence to the diet is essential to its overall success (19,24). In this study, we also found a positive correlation between adherence and symptom improvement. In addition, adherent patients had a significant improvement in 17/20 rated symptoms, compared with only 7/20 symptoms in less adherent patients. Several factors contribute to adherence with the diet, including its ease of use and the absence of barriers such as the perceived taste of the diet. Despite that, most participants do not find the diet easy to incorporate in their life, which may explain why only 12.2% of the patients report complete adherence. However, even with a mean follow up of 15.7 (± 9.0) months, the majority of patients remain adherent suggesting that the perceived difficulties are worth the improvement in symptoms.

Most patients had two consultations with the dietitian and indicate that the consultation(s) and written information are the most important supporting factors in maintaining adherence. Because of similarities between the Australian and New Zealand diets and food choices, minimal adaptation of the diet was required for use in New Zealand. A minority of patients believe that the diet would be effective if given in written form only. It is also interesting to note that patients believe that the results of undergoing breath testing help to maintain adherence to the low FODMAP diet. Given that adherence to the diet is associated with efficacy, undergoing breath testing may improve outcomes.

Almost 75% of patients were satisfied with their symptoms after breath tests and dietary intervention – similar to that published by Staudacher et al.

While this represents a significant improvement, one quarter are not satisfied with their symptoms. Therefore, while the low FODMAP diet may help many IBS patients, other approaches are needed. Targets for improving treatment include optimising adherence to this and other dietary approaches or else exploring other non-dietary strategies.

Although this study suggests that the low FODMAP diet is effective for many IBS patients, there are limitations to this study. First, the response rate of 46.9% was lower than hoped for and reflects high rates of migration out of our region since the Christchurch earthquakes. This lower response rate may reduce the generalisability of the results, particularly if those who took part in the study and those who did not are in any way different. However, when the demographic and symptom profiles of the responders and non-responders are compared, the only significant difference is a higher proportion of women among the responders. This may have led to a small differential bias because male patients with abdominal pain were less likely than female patients to respond to a low FODMAP diet. However, this difference was not seen for any other symptom. Furthermore, if all of the non-responders are included in the analysis as not having responded to the diet (i.e. assigned the same follow-up symptom scores as baseline), the results remained significant.

Secondly, this is a non-randomised observational study with the potential for a placebo effect from the intervention. However, the observed improvement in symptoms is biologically plausible because of the mechanisms that have been described and the symptoms with less biological plausibility (passage of mucous, early satiety and burping) did not show a

significant improvement. Furthermore, a randomised placebo-controlled crossover rechallenge study showed efficacy of the diet in a small cohort (7).

In conclusion, this study supports the efficacy of a low FODMAP diet in improving symptoms in IBS patients. Those with fructose malabsorption are most likely to benefit. Furthermore, the current strategy of dietary advice being delivered by trained dietitians following hydrogen breath testing provides a good base for patients to understand and adhere to the diet, which is essential for its success.

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Author contributions

Reinout de Roest: Formulation of research plan and hypotheses, data extraction and collection, statistical analyses and writing the manuscript. Bruce Dobbs, Bruce Chapman: Interpretation of statistical analyses and feedback concerning the manuscript. Birol Batman: Formulation of research plan, data extraction and collection. Leigh O'Brien, Julie Leeper, Clarice Hebblethwaite: Formulation of research plan, delivery of dietary advice, feedback on the manuscript. Richard Geary: Formulation of research plan, supervision of Reinout de Roest, interpretation of statistical analyses and feedback concerning the manuscript.

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