RESEARCH
Review

Understanding the Physics of Functional Fibers in the Gastrointestinal Tract: An Evidence-Based Approach to Resolving Enduring Misconceptions about Insoluble and Soluble Fiber

Johnson W. McRorie, Jr, PhD; Nicola M. McKeown, PhD

ARTICLE INFORMATION

Article history:
Submitted 22 February 2016
Accepted 20 September 2016
Available online 15 November 2016

Keywords:
Fiber
Insoluble
Soluble
Misconceptions
Health benefits

http://dx.doi.org/10.1016/j.jand.2016.09.021

ABSTRACT

Enduring misconceptions about the physical effects of fiber in the gut have led to misunderstandings about the health benefits attributable to insoluble and soluble fiber. This review will focus on isolated functional fibers (eg, fiber supplements) whose effects on clinical outcomes have been readily assessed in well-controlled clinical studies. This review will also focus on three health benefits (cholesterol lowering, improved glycemic control, and normalizing stool form [constipation and diarrhea]) for which reproducible evidence of clinical efficacy has been published. In the small bowel, clinically meaningful health benefits (eg, cholesterol lowering and improved glycemic control) are highly correlated with the viscosity of soluble fibers: high viscosity fibers (eg, gel-forming fibers such as b-glucan, psyllium, and raw guar gum) exhibit a significant effect on cholesterol lowering and improved glycemic control, whereas nonviscous soluble fibers (eg, inulin, fructooligosaccharides, and wheat dextrin) and insoluble fibers (eg, wheat bran) do not provide these viscosity-dependent health benefits. In the large bowel, there are only two mechanisms that drive a laxative effect: large/coarse insoluble fiber particles (eg, wheat bran) mechanically irritate the gut mucosa stimulating water and mucous secretion, and the high water-holding capacity of gel-forming soluble fiber (eg, psyllium) resists dehydration. Both mechanisms require that the fiber resist fermentation and remain relatively intact throughout the large bowel (ie, the fiber must be present in stool), and both mechanisms lead to increased stool water content, resulting in bulky/soft/easy-to-pass stools. Soluble fermentable fibers (eg, inulin, fructooligosaccharide, and wheat dextrin) do not provide a laxative effect, and some fibers can be constipating (eg, wheat dextrin and fine/smooth insoluble wheat bran particles). When making recommendations for a fiber supplement, it is essential to recognize which fibers possess the physical characteristics required to provide a beneficial health effect, and which fiber supplements are supported by reproducible, rigorous evidence of one or more clinically meaningful health benefits.
J Acad Nutr Diet. 2017;117:251-264.

IN 2002, THE INSTITUTE OF MEDICINE PUBLISHED A definition of total fiber that differentiated dietary fiber (ie, nondigestible carbohydrates and lignin that are intrinsic and intact in plants) from functional fiber (ie, isolated, nondigestible carbohydrates that have been shown to have beneficial physiologic effects in humans).[1] By this definition, the isolated nondigestible carbohydrates found in fiber supplements must show clinical evidence of a health benefit to be considered a functional fiber. The term *fiber supplement* may lead health care professionals and/or consumers to believe that regular consumption will provide health benefits that may be missing from a low-fiber diet. For many fiber supplements, this belief is not supported by reproducible, well-controlled clinical evidence of a health benefit. It is therefore important to understand which fiber supplements have clinical evidence of a meaningful health benefit, and which do not.

Although observational studies have reported health benefits associated with high intakes of dietary fiber from whole foods, such as a reduced risk of developing colorectal cancer,[2] enhanced immune function,[3] and less weight gain over time,[4] the lack of establishing causality is a recognized limitation of

these studies. Further, attributing the specific beneficial effects to the dietary fiber component of whole foods, as opposed to the effects of other health-promoting constituents, is a daunting task. This review will focus on the beneficial effects of the isolated functional fibers found in fiber supplements, which are readily assessed for efficacy and mechanism of action in well-controlled, randomized clinical trials (RCTs). The review will provide an objective assessment of the totality of evidence from RCTs on three health benefits for which reproducible evidence of clinical efficacy have been published: lowering elevated serum cholesterol concentrations, improving glycemic control, and normalizing stool form in constipation and diarrhea.

METHODS

A comprehensive literature review was conducted with the use of the Scopus and PubMed scientific databases, without limits to year of publication (latest date included: July 9, 2016). Key search words included: *fiber*, *inulin*, *dextrin*, *wheat dextrin*, *resistant maltodextrin*, *guar gum*, *oat*, *oat bran*, *b-glucan*, *barley*, *psyllium*, *ispaghula*, *polydextrose*, *soluble corn fiber*, *methylcellulose*, *fructooligosaccharide*, *galactooligosaccharide*, *oligofructose*, *laxation*, *laxative*, *constipation*, *stool*, *water content*, *bran*, *wheat bran*, *soluble*, *insoluble*, *cholesterol*, *glycemic*, *blood glucose*, and *postprandial*. Published clinical studies were identified, and assessed for study design, study population, and fiber dose. The reference section of each identified publication was also searched for any studies that might have been missed in the database searches.

Professional recommendations are ideally based on rigorous, reproducible clinical data, so only those studies that were randomized to treatment, and assessed treatment effects vs a concurrent (parallel or crossover) control group (eg, placebo) were considered for inclusion in this review. Sequential studies that assessed a change from baseline in a metabolic risk factor were not included in the review because they do not account for period effects (a placebo treatment group can also show a significant change from baseline). We also decided to exclude one study because we were concerned about the results. The study by Dehghan and colleagues[5] assessed oligofructose-enhanced inulin (10 g/day) in 46 Iranian women with type 2 diabetes. Because the magnitude of the reported results were extreme outliers (eg, low-density lipoprotein [LDL] cholesterol level decreased from 116 mg/dL [3.0 mmol/L] to 37±97 mg/dL [0.96±2.51 mmol/L]), far exceeding the effects observed with a high dose/high-impact statin drug,[6] we believed we were justified in not including this article in our review.

RESULTS

Misconception #1: All Soluble Fibers Lower Elevated Serum Cholesterol Levels

Although it is true that some soluble fibers can effectively lower elevated serum cholesterol concentrations, it is not true that all soluble fibers have this effect. As will be discussed in the following paragraphs, only highly viscous soluble fibers (eg, gel-forming fibers such as b-glucan, psyllium, and raw guar gum) have been shown to exhibit this viscosity-dependent health benefit. Isolated functional fibers have unique characteristics based on the way in which the polymer sugar chains interact with one another (eg, highly branched vs straight chains).[7] Highly branched, bush-like polymers with multiple branches at irregular intervals do not pack in a regular array, have no significant effect on viscosity, and are referred to as nonviscous (eg, inulin, fructooligosaccharides, and wheat dextrin). In contrast, straight-chain or linear polymers can pack into a regular array, and the longer the straight chain, the greater the effect on viscosity (see the Figure). A linear polymer in which the adjacent chains form cross-links can form a gel (eg, b-glucan, psyllium, and raw guar gum) (see the Figure).

It has been hypothesized that soluble, nonviscous, fermentable fibers (eg, inulin, fructooligosaccharides), also referred to as prebiotics, can normalize blood lipid concentrations via the byproducts of fermentation.[1] Although lipid-lowering effects for inulin and oligofructose have been observed in rodents, the fiber dose administered in these studies was very high (50 to 200 g/kg body weight per day).[8] To put this in perspective, a comparable dose for a 75-kg person would be 3,750 to 15,000 g (3.7 to 15 kg) of readily fermented fiber per day, several orders of magnitude above a reasonable/tolerable dose. The 2002 Dietary Reference Intake (DRI) guidelines for fiber suggest that fermentable inulin and oligofructose could normalize blood lipid concentrations.[1] The DRI authors did acknowledge that the results for this health effect were mixed, but the studies they cited showed a single positive effect on one lipid (ie, triacylglycerol) without acknowledging that the same studies failed to show a significant difference for total cholesterol and LDL cholesterol.[9-11] A review of the available published literature yielded 17 randomized, well-controlled clinical studies that assessed the effects of soluble nonviscous, fermentable fibers on blood lipid concentrations, and none of these studies showed a significant difference in total and LDL cholesterol compared with the placebo control (Table 1).[9-25] Of these 17 studies, seven were published before 2002 (1997-2000) and were available for consideration in the DRI document.[9-12,14,16,23] The additional 10 studies were published after 2002 (2003-2013), representing new information.[13,15,17-22,24,25] Of the 16 studies that assessed the triglyceride-lowering effects of soluble nonviscous fermentable fibers, 13 showed no effect of the fiber compared with the placebo on triglyceride levels. It should be noted that if one looks across numerous studies, each with multiple end points assessed for a *P* value of 0.05, a few of those end points can show a statistically significant difference

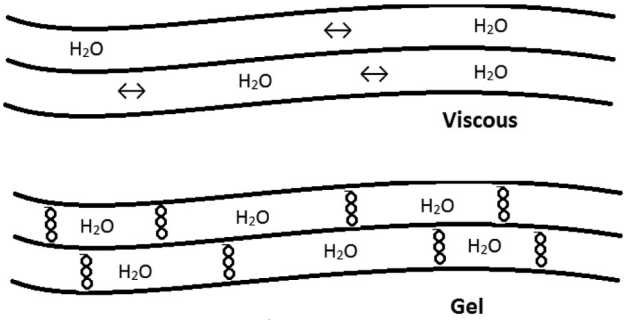

Figure. Viscous and gel-forming linear polymers. Drawings represent viscous linear polymers (top) and gel-forming linear polymers (bottom).

Table 1. Nonviscous fermentable soluble fibers have no effect on lipid metabolism or glycemic control

Reference	Study design, duration of treatment	Fiber (dose) [subjects]	Significant reduction in total cholesterol and low-density lipoprotein cholesterol vs placebo?	Significant reduction in triglycerides vs placebo?	Significant reduction in postprandial and/or fasting blood glucose vs placebo?
Causey and colleagues[12]	RCT[a], crossover, 3 wk	Inulin (20 g/d) [12 hyperlipidemia]	No	No	No
Giacco and colleagues[13]	RCT, crossover, 2 mo	FOS[b] (10.6 g/d) [30 hyperlipidemia]	No	No	No
Alles and colleagues[14]	RCT, crossover, 20 d	FOS (15 g/d) [20, T2DM[c]]	No	No	No
Jackson and colleagues[9]	RCT, parallel, 8 wk	Inulin (10 g/d) [54 middle-aged]	No	Yes	No
Letexier and colleagues[15]	RCT, crossover, 3 wk	Inulin (10 g/d) [8 healthy]	No	Yes	No
Pedersen and colleagues[10]	RCT, crossover, 4 wk	Inulin (14 g/d) [64 healthy]	No	No	—
Luo and colleagues[11]	RCT, crossover, 4 wk	FOS (20 g/d) [12 healthy]	No	No	No
Luo and colleagues[16]	RCT, crossover, 4 wk	FOS (20 g/d) [10 T2DM]	No	No	No
Forcheron and Beylot[17]	RCT, parallel, 6 mo	Inulin/FOS mix (10 g/d) [17 healthy]	No	No	No
De Luis and colleagues[18]	RCT, parallel, 1 mo	FOS (10 g/d) [38 obese]	No	No	No
Dewulf and colleagues[19]	RCT, parallel, 3 mo	Inulin/FOS mix (16 g/d) [30 obese]	No	No	No
Parnell and Reimer and colleagues[20]	RCT, parallel, 12 wk	FOS (21 g/d) [48 obese]	No	—	No
Tovar and colleagues[21]	RCT, parallel, 3 mo	Inulin (10 g/d) [144 obese]	No	No	No
Vulevic and colleagues[22]	RCT, crossover, 12 wk	GOS[d] (5.5 g/d) [45 MS[e]]	No	Yes	No
Davidson and colleagues[23]	RCT, crossover, 6 wk	Inulin (18 g/d) [25 hyperlipidemia]	No	No	—
Russo and colleagues[24]	RCT, crossover, 5 wk	Inulin (11 g/d) [22 healthy]	No	No	—
Daubioul and colleagues[25]	RCT, crossover, 8 wk	OF[f] (16 g/d) [7 NASH[g]]	No	No	No

[a]RCT=randomized controlled trial.
[b]FOS=fructooligosaccharide.
[c]T2DM=type 2 diabetes mellitus.
[d]GOS=galactooligosaccharide.
[e]MS=metabolic syndrome.
[f]OF=oligofructose.
[g]NASH=nonalcoholic steatohepatitis.

vs placebo by random chance. The few positive outliers must be viewed in the context of the totality of available well-controlled clinical evidence. Taken together, the totality of reproducible well-controlled clinical evidence shows that nonviscous fermentable fibers have no effect on lipid metabolism, and debunks the concept that nonviscous fermentable fibers normalize blood lipid levels (eg, total cholesterol, LDL cholesterol, and triglycerides) via byproducts of fermentation.

In contrast to nonviscous fibers, the importance of viscosity was clearly demonstrated in a well-controlled clinical study that compared the cholesterol-lowering effectiveness of several different viscosities of b-glucan, a gel-forming soluble fiber.[26] In this double-blind, parallel-design, multicenter clinical study, 386 subjects were randomly assigned to receive cereal containing insoluble wheat bran (negative control) or one of three gel-forming oat bran cereals (3 to 4 g/day b-glucan that was high, medium, or low viscosity).[26] The degree of processing (heat and pressure for extrusion) was used to lower the normally high viscosity of gel-forming b-glucan. The results showed that cholesterol lowering was highly correlated with the viscosity of the gel-forming fiber: the high-viscosity gel (low heat and pressure processing) exhibited significant LDL-cholesterol lowering (−5.5%; $P<0.05$ vs bran placebo), as did the medium-viscosity gel (−4.7%; $P<0.05$), whereas the lower viscosity b-glucan did not exhibit a significant cholesterol-lowering effect.[26] A similar study assessed the cholesterol-lowering effects of raw oat b-glucan in orange juice (5.0 g/day) vs the same fiber baked into bread (5.9 g/day).[27] Only the raw b-glucan significantly decreased LDL cholesterol (−6.7%; $P<0.001$) vs insoluble wheat bran (placebo control).[27] These data show the importance of considering not only the specific fiber, but also the degree of processing for the final marketed product. Note that both nonviscous soluble fibers and insoluble fiber do not provide this viscosity-dependent health benefit, and can be used as a negative control (ie, placebo).[26,28-30]

The primary mechanism by which a gel-forming fiber lowers serum cholesterol levels is by trapping and eliminating bile via the stool.[31] Bile is produced by the liver, stored and concentrated in the gall bladder, and released into the small bowel in response to a meal. Bile facilitates the digestion and absorption of dietary lipid levels, and is normally recovered in the terminal ileum and recycled, up to several times within a given meal.[7] In contrast to nutrient absorption, which can occur along the entire length of the small bowel, the recovery of bile is limited to the terminal ileum, providing only a brief opportunity for bile reabsorption. A gel-forming fiber becomes more concentrated as water is reabsorbed along the length of the small bowel, causing it to become more viscous, trapping bile (interfering with reabsorption). The trapped bile is eliminated via the stool.[7] The reduction in the bile acid pool causes hepatocytes to compensate by stimulating LDL receptor expression/increasing LDL cholesterol clearance to synthesize more bile acids (cholesterol is a component of bile) and maintain sufficient bile for digestion. This clearance of LDL cholesterol from the blood effectively lowers serum LDL cholesterol and total cholesterol concentrations, without significantly affecting high-density lipoprotein cholesterol concentration.[7,31] Only gel-forming fiber supplements (eg, high-molecular-weight b-glucan, raw guar gum, and psyllium), consumed with meals to coincide with bile release, have the requisite high viscosity to effectively lower elevated serum cholesterol concentrations.[7,26,28,31-33]

It is important to note that not all viscous fibers can effectively lower elevated serum cholesterol concentrations. A placebo-controlled, randomized, parallel study (105 patients with hypercholesterolemia) assessed the cholesterol-lowering effects of psyllium (a natural gel-forming fiber) vs methylcellulose (a semisynthetic viscous soluble fiber made from wood pulp) and polycarbophil (a synthetic polymer).[34] The subjects received one of the three treatments three times a day for 8 weeks. The results showed that LDL cholesterol concentrations were significantly lower with gel-forming psyllium (−8.8%; $P=0.02$) vs placebo, but not for methylcellulose or calcium polycarbophil.[34] The effectiveness of psyllium for lowering elevated serum cholesterol levels has been assessed in 21 randomized, well-controlled clinical studies (more than 1,500 subjects) at doses of 6 to 15 g/day (most studies at 10 g/day), with all studies showing significant cholesterol-lowering effects, ranging from −2% to −20% for total cholesterol, and −6% to −24% for LDL cholesterol, vs placebo.[33-53] The efficacy of psyllium tended to be greatest in studies assessing patients with a high baseline cholesterol concentration, and in studies where the diet was not restricted. Note that the cholesterol-lowering benefit for psyllium is also additive to the effects of both statin drugs and bile acid sequestrants.[54-59]

In summary, cholesterol-lowering efficacy is highly dependent on the viscosity of the hydrated fiber: The higher the viscosity, the greater the potential effect on lowering elevated blood cholesterol concentrations. The viscosity of a gel-forming fiber can actually be a better predictor of cholesterol-lowering efficacy than the quantity of fiber consumed.[30] Insoluble fiber (eg, wheat bran), low-viscosity soluble fiber (eg, gum Arabic/acacia gum, methylcellulose, or low-molecular-weight b-glucan) and nonviscous soluble fermentable fiber (eg, inulin, fructooligosaccharides, and wheat dextrin) supplements do not exhibit a significant cholesterol-lowering benefit at physiologic doses. Note that b-glucan and psyllium, both gel-forming fibers, are the only two fibers with a Food and Drug Administration-authorized health claim to reduce the risk of cardiovascular disease by lowering serum cholesterol levels.[60] Taken together, the totality of clinical evidence debunks the concept that nonviscous fermentable fibers normalize blood lipid levels via byproducts of fermentation. Only high-viscosity fibers provide this health effect, so it is important to consider not only the type of fiber to recommend, but also the degree of processing (eg, heat/pressure extrusion into cereal shapes) that may attenuate the efficacy of marketed products.

Misconception #2: All Soluble Fibers Improve Glycemic Control

Although it is true that some soluble fibers improve glycemic control, it is not true that all soluble fibers have this beneficial effect. Similar to the effects of high-viscosity fiber supplements on elevated serum cholesterol concentrations, improving glycemic control is a viscosity-dependent phenomenon. The 2002 DRI guidelines for fiber suggested that fermentable inulin and oligofructose could attenuate blood glucose responses, again citing a few human studies with a

single positive end point.[1] The 14 randomized, well-controlled clinical studies listed in Table 1 show that none of the fructans (ie, inulin, fructooligosaccharide, galactooligosaccharide, and oligofructose) showed evidence of improved glycemic control vs placebo. Based on the totality of evidence from 14 randomized, well-controlled, reproducible clinical studies, it is reasonable to conclude that soluble nonviscous fermentable fibers do not attenuate blood glucose responses or improve glycemic control.

In contrast to the above-mentioned nonviscous fibers, it was demonstrated more than 3 decades ago that the effectiveness of soluble fiber on glucose and insulin metabolism is proportional to the viscosity of the hydrated fiber.[61] In a study published in 1978,[61] volunteers consumed 50 g liquid glucose with and without highly viscous raw guar gum. The high-viscosity (gel-forming) fiber exhibited a clinically meaningful decrease in postprandial blood glucose and insulin concentrations compared with liquid glucose alone. The beneficial effect on postprandial measures was abolished when the guar gum was hydrolyzed to a nonviscous form. After comparing several gelling fibers of different viscosities, the authors concluded that the reduction in postprandial blood glucose level was highly correlated with the viscosity of the hydrated fiber (r=0.926; P<0.01).[61] A challenge with consumption of raw guar gum is that it rapidly forms a tight gel, rendering it unpalatable when hydrated. In an attempt to make guar gum more palatable, manufacturers hydrolyze the guar gum (eg, partially hydrolyzed guar gum), resulting in a low viscosity/nonviscous product. As discussed above, this processing renders the guar gum ineffective for viscosity-dependent health benefits like cholesterol lowering and improved glycemic control, so it is important to consider processing when recommending a fiber supplement.

Although postprandial glucose studies are a useful tool for assessing acute glycemic effects, long-term (multimonth) data from well-controlled intervention clinical studies are necessary to establish a clinically meaningful health benefit for improved glycemic control. Several multimonth clinical studies have demonstrated that consumption of a soluble, viscous, fiber supplement (eg, gel-forming fibers such as psyllium and guar gum), dosed with meals, can improve glycemic control (lower fasting blood glucose, insulin, and glycated hemoglobin levels) in subjects at risk for developing type 2 diabetes, and patients being treated for type 2 diabetes.[7,31,38-40,62-64]

The primary mechanism for improving glycemic control with a soluble, viscous fiber supplement is by significantly increasing the viscosity of chyme in a dose-dependent manner.[63] The increased viscosity slows interactions of digestive enzymes and nutrients, which slows the degradation of complex nutrients into absorbable components, and slows the absorption of glucose and other nutrients at the brush border.[7,31] Nutrients are normally absorbed early in the small bowel, but the increase in chyme viscosity and slowing of nutrient degradation/absorption can lead to increased delivery of nutrients to the distal ileum, where nutrients are normally not present or only minimally present. Nutrients delivered to the distal ileum can stimulate mucosal L-cells to release glucagon-like peptide-1 into the bloodstream.[7] Glucagon-like peptide-1 is a short-lived (approximately 2-minute half-life) peptide that significantly decreases appetite, increases pancreatic beta-cell growth (cells that produce insulin), improves insulin production and sensitivity, and decreases glucagon-secretion (a peptide that stimulates glucose production in the liver). Delivery of lipids, carbohydrates, and protein to the distal ileum can also stimulate the ileal brake phenomenon, which has been defined as "…a distal to proximal feedback mechanism to control transit of a meal through the gastrointestinal tract in order to optimize nutrient digestion and absorption."[65] Slowing gastric emptying and small bowel transit via the ileal brake has been shown to reduce both hunger and food intake.[65] It is important to note that although a viscous fiber can slow the absorption of nutrients, it does not reduce total nutrient absorption.[66] Unlike bile, which is only absorbed in a short segment of the distal ileum, nutrients are absorbed along the entire 7-m length of the small bowel, providing ample opportunity for nutrient absorption to occur.[7,31] The ileal brake phenomenon can effectively slow gastric emptying and small bowel transit to attenuate the loss of nutrients to the large bowel.[7,31,65]

Similar to cholesterol lowering, the long-term glycemic effects of viscous/gel-forming fiber are also proportionate to baseline glycemic control,[67] no significant effect in euglycemia,[36,43,47] a modest effect in prediabetes/metabolic syndrome (eg, −19.8 mg/dL [−1.1 mmol/L] for psyllium 3.5 g two times per day and −9 mg/dL [−0.5 mmol/L] for guar gum 3.5 g two times per day)[38] and the greatest effect in patients being treated for type 2 diabetes mellitus (eg, psyllium, −35.0 to −89.7 mg/dL [−1.9 mmol/L to −4.98 mmol/L]).[39,62,63] Taken together, these studies show that improved glycemic control is proportionate to the viscosity of a hydrated fiber (eg, gel-forming raw guar gum, high-molecular-weight b-glucan, and psyllium). Insoluble fiber (eg, wheat bran and cellulose) and soluble nonviscous fibers (eg, inulin, wheat dextrin, polydextrose, soluble corn fiber, and resistant maltodextrin) do not provide these viscosity-dependent health benefits at physiologic doses.

Misconception #3a: All Fibers Provide a Regularity Benefit

Regularity can be defined as the regular (eg, daily) elimination of bulky/soft/easy-to-pass stools. Constipation can be defined as infrequent (<3 bowel movements [BMs] per week) elimination of small/hard stools that are difficult to pass.[7] Normal BM frequency is considered to be at least three BMs per week to 3/day.[7] Although BM frequency is often used as a measure of regularity, it should not be the primary measure. For example, one person may strain to pass a single small, hard marble-like stool every day (eg, 7 BMs/wk), whereas another may have a bulky/soft/easy-to-pass stool every other day (eg, 3 to 4 BMs/wk). In this instance, the person with the higher BM frequency is constipated, whereas the other is not. The most important consideration for assessing a clinically meaningful regularity benefit with increased fiber consumption is evidence of a significant increase in both stool output (assessed as grams of stool per day for healthy subjects, can be assessed as grams per week in chronic constipation) and stool water content (%). Stool water content is highly correlated with stool consistency, and is the mechanism for both a stool softening effect and a stool bulking effect.[7,68] There are two mechanisms by which fiber can provide a significant regularity benefit (laxative effect): large/

coarse insoluble fiber particles (eg, wheat bran) have a mechanically irritating effect on large bowel mucosa, stimulating secretion of water and mucous, and soluble gel-forming fiber (eg, psyllium) has a high water-holding capacity that resists dehydration in the large bowel.[7,68] For both mechanisms, fiber must resist fermentation to remain intact and present throughout the length of the large bowel (must be present in stool; prerequisite #1), and fiber must increase stool water content (prerequisite #2) leading to bulky/soft stools that are easy to pass.[7,31] An appreciation for the strong correlation between stool water content and stool consistency can provide insights into why some functional fibers provide an effective regularity/laxative benefit, why some do not, and how some functional fibers can actually have a constipating effect.

Digesta is normally a liquid (≥90% water) when it arrives in the cecum, and it is gradually dehydrated along the entire length of the large bowel, resulting in formed stool (≈75% water content) in the rectum.[7,31,68] As discussed above, when considering the regularity/laxative effects of fiber in the large intestine, the isolated fiber must meet two prerequisites to provide a significant benefit. A fiber must resist fermentation to remain relatively intact and present throughout the length of the large bowel (be present in stool) because transit through the large bowel normally takes 1 or more days, and the large bowel is quite efficient at absorbing water along its entire length. A fiber that is readily fermented in the proximal large bowel cannot significantly affect the water content of stool in the distal bowel 1 or more days later. Exposure of the stool to the mucosa throughout the remainder of the large bowel, without the presence of intact fiber, would result in significant stool dehydration. A fiber must significantly increase the percent water content of stool, which is the primary driver for both softening stool and increasing stool bulk.[68,69] The water content of stool is inversely proportional to stool viscosity.[68,69]

As stool water content decreases, stool viscosity increases exponentially: liquid stool is ≈90% water content; soft stool is ≈77% water; formed stool is ≈75% water, and hard stool is ≤72% water.[7,31,68-70] This 18% difference in stool water content (from 90% to 72%) represents a 240-fold increase in stool viscosity (from liquid to hard).[7,68-70] By increasing stool water content, an effective fiber therapy will keep stools soft/formed, and significantly increase stool bulk, both of which make stools easy to pass without straining. An ineffective fiber would either have no significant effect on stool water content/stool bulk, or would add to the dry mass of stool, which would decrease the percentage of stool water content and result in harder stools. The following sections will discuss different fiber types (eg, insoluble fiber, soluble gel-forming fiber, and soluble nonviscous fiber) as they relate to a regularity benefit/laxative effect.

Although it is true that some fibers provide a regularity/laxative benefit, it is not true that all fibers have this effect. As with normalizing blood lipid levels and attenuating glucose response, the DRI guidelines cite a few studies that suggest a laxative effect for inulin, oligofructose, and fructooligosaccharides. In theory, fermentable fibers would increase the mass of bacteria, thereby increasing stool output. In contrast to this theory, data from well-controlled RCTs show that fermentable fibers have no effect on stool output or stool softening. Table 2 summarizes the results from 21 well-controlled RCTs that assessed the laxative effects (stool output, stool softening, and/or BM frequency) of nonviscous soluble fermentable fibers.[71-87] Of the 15 studies that assessed stool output, 14 showed no effect of the fermentable fibers compared with the placebo. One study in 36 healthy subjects showed that a high dose of polydextrose (20 g/day for 10 days) resulted in a minimal (2 g stool per gram fiber; 2 g/g) but statistically significant effect on stool output.[83] In contrast, a similar study in 21 healthy adults, with a higher dose (21 g/day) of polydextrose for 3 weeks, showed no effect on stool output.[81] In addition, four other studies with more reasonable doses (4 to 12 g/day) for 3 to 4 weeks also failed to show a significant effect of polydextrose on stool output or other regularity/laxative outcome measures compared to the placebo.[72,82,86,87] Of the 21 studies that assessed a stool softening effect, 20 showed no effect of the fiber compared with the placebo (Table 2).

Of the 17 studies that assessed BM frequency, 14 showed no effect with fermentable fibers. The 3 studies that exhibited a small increase in BM frequency administered a relatively high fiber dose (inulin 15 g/day, soluble corn fiber 20 g/day, and polydextrose 20 g/day), yet studies with a similar or higher dose of the same fibers failed to demonstrate this effect (Table 2). Further, an increase in BM frequency without a significant increase in daily stool output, and a significant stool softening effect, means that each BM produced smaller, potentially harder stools. As described previously, more frequent BMs with smaller/harder stools is not a health benefit. The totality of clinical evidence supports that fermentable fibers do not provide a laxative effect/regularity benefit. Further, at least one soluble fermentable fiber, wheat dextrin, has been shown to have a constipating effect.[84,85] Two well-controlled crossover clinical studies showed that 10 to 15 g/day wheat dextrin resulted in a decrease in stool output and a decrease in stool water content (smaller/harder stools), as well as subjective reports of harder stools by healthy subjects.[84,85] One additional soluble fiber, methylcellulose (semisynthetic; chemically treated wood pulp), was not included in Table 2 because it is viscous and not fermented in the human gut. Methylcellulose has an over-the-counter indication for regularity, but no well-controlled clinical studies were identified to support a laxative effect in constipation. One study that assessed a change from baseline in healthy subjects failed to show a dose-response in stool output across a fourfold increase in the dose of methylcellulose.[88] The totality of clinical evidence debunks the concept that all fibers provide a regularity benefit.

Misconception #3b: Insoluble Fiber has High Water-Holding Capacity (Holds Water Like a Sponge) that Provides a Regularity/Laxative Benefit

For insoluble fiber, there continues to be a misconception that the observed increase in stool water content associated with its laxative effect is due to water-holding capacity.[89-91] In reality, insoluble fiber has no significant interaction with water and no appreciable water-holding capacity in the large bowel, yet it can significantly increase both stool water content (soften stools) and stool bulk.[92] The question is, How? The answer: Insoluble particles have a mechanically irritating effect on the mucosa of the large bowel, stimulating secretion of water and mucous as a defense mechanism to protect from abrasion.[7,92] Insoluble fiber (eg, wheat bran) is

Table 2. Particulars of studies[71-87] showing fermentable fibers have no significant effect on objective measures of regularity/laxation

Reference	Study design, duration of treatment	Fiber dose (subjects)	Significant increase in stool output vs placebo?	Significant stool softening effect vs placebo?	Significant bowel movement frequency increase vs placebo?
Inulin					
Slavin and Feirtag[71]	RCT[a], crossover, 3-wk	20 g/d (12 healthy)	No	No	No
Costabile and colleagues[73]	RCT, crossover, 3-wk	10 g/d (32 healthy)	—	No	No
Van Dokkum and colleagues[74]	RCT, crossover, 3-wk	15 g/d (12 healthy)	No	No	—
Ramnani and colleagues[75]	RCT, parallel, 3-wk	5 g/d (66 healthy)	—	No	No
Kleesen and colleagues[76]	RCT, parallel, 2-wk	15 g/d (45 healthy)	—	No	No
Waitzburg and colleagues[77]	RCT, parallel, 3-wk	15 g/d (60 constipated)	—	—	No
Marteau and colleagues[78]	RCT, parallel, 4-wk	15 g/d (50 constipated)	—	No	No
Dahl and colleagues[79]	RCT, crossover, 3 wk	13 g/d (15 institutionalized)	—	—	No
Den Hond and colleagues[80]	RCT, crossover, 1-wk	15 g/d (6 healthy)	No	No	Yes[b]
Soluble corn fiber					
Boler and colleagues[81]	RCT, crossover, 3-wk	21 g/d (21 healthy)	No	No	—
Stewart and colleagues[82]	RCT, crossover, 2-wk	12 g/d (20 healthy)	No	No	No
Timm and colleagues[83]	RCT, crossover, 10-d	20 g/d (36 healthy)	No	No	Yes[b]
Dextrin					
Van den Heuvel and colleagues[84]	RCT, crossover, 1-wk	WD[c] 10 and 15 g/d (20 healthy)	No	No	No
Van den Heuvel and colleagues[85]	RCT, crossover, 1-wk	WD 10 and 15 g/d (20 healthy)	No	No	No
Stewart and colleagues[82]	RCT, crossover, 2-wk	SD[d] 12 g/d (20 healthy)	No	No	No
Polydextrose					
Costabile and colleagues[72]	RCT, crossover, 3-wk	8 g/d (31 healthy)	No	No	No
Boler and colleagues[81]	RCT, crossover, 3-wk	21 g/d (21 healthy)	No	No	—
Jie and colleagues[86]	RCT, parallel, 4-wk	4, 8, and 12 g/d (120 healthy)	No	No	No
Hengst and colleagues[87]	RCT, parallel, 3-wk	8 g/d (45 healthy)	No	No	—
Timm and colleagues[83e]	RCT, crossover, 10-d	20 g/d (36 healthy)	Yes	Yes	Yes
Resistant starch					
Stewart and colleagues[82]	RCT, crossover, 14-d	12 g/d (20 healthy)	No	No	No

[a]RCT=randomized controlled trial.
[b]An increase in bowel movement frequency without an increase in stool output and stool water content means each bowel movement produced a smaller, potentially harder stool, which is not a health benefit.
[c]WD=wheat dextrin.
[d]SD=soluble dextrin.
[e]A high-dose (20 g/d) outlier study with nonreproducible results. Other studies of polydextrose failed to show an effect, even at a higher dose (Boler and colleagues[81]).

poorly fermented, so it remains relatively intact and present throughout the large bowel (prerequisite #1).[92] The observation that coarse wheat bran had a greater laxative effect than fine wheat bran suggested that the insoluble particles themselves may have a direct effect in the large bowel.[93] This observation led to several studies comparing insoluble wheat bran to swallowed inert plastic particles (plastic effect) at the same grams per day dose as the wheat bran.[94-96] Note that plastic particles have no water-holding capacity and are not fermented by bacteria, so any observed laxative effect would be purely mechanical in nature.

The studies clearly showed that swallowed plastic particles, cut to match the size and shape of wheat bran particles milled to different sizes, exhibited the same laxative effect: large/coarse particles had a profound laxative effect, whereas small/smooth particles had no effect.[94-96] These studies confirmed that the laxative effect of insoluble fiber was due to mechanical irritation of the mucosa, causing secretion of water and mucous, leading to bulky/soft/easy-to-pass stools. One study assessed finely ground wheat bran and showed that it added to the dry mass of stool, effectively lowering the percent stool water content, which led to harder stools and reports from healthy subjects that they developed difficult/uncomfortable BMs during the wheat bran treatment period (constipating effect).[97]

In summary, for both coarse wheat bran and coarse plastic particles, the observed increase in stool output and the stool softening effect were due to mechanical irritation of the large bowel mucosa (plastic effect), stimulating secretion of water and mucous. Large/coarse particles can provide a significant laxative effect/regularity benefit, whereas fine/smooth particles can have a constipating effect, providing a rationale for why laxative-effect clinical data for insoluble fiber may appear inconsistent. When considering insoluble fiber for a clinical study or professional recommendation, attention must be paid to the particle size/coarseness of the final marketed product. Further, the lack of water-holding capacity and the mucosa irritating effect make insoluble fiber a poor choice for attenuating symptoms in irritable bowel syndrome.[98,99]

Misconception #3c: All Soluble Fermentable Fibers Provide a Regularity Benefit/Laxative Effect by Increasing the Biomass

Although it is true that consumption of some fermentable fibers can cause increases and decreases in specific bacteria (eg, prebiotic effect), it is a misconception that these relatively small opposing changes to a few specific bacteria provide a significant regularity/laxative benefit. Fibers that are readily fermented do not remain intact and present throughout the large bowel (do not meet prerequisite #1) and have no significant water-holding capacity in the large bowel (do not meet prerequisite #2), so mechanistically would not be expected to provide a regularity benefit. As discussed in section 3a, the totality of well-controlled clinical evidence shows that soluble fermentable fibers have no effect on stool output (Table 2).

Similarly, many gel-forming soluble fibers (eg, b-glucan, guar gum, and xanthan gum) are readily fermented in the large bowel, resulting in the loss of both their gelled nature and their water-holding capacity.[7,92,100,101] At extreme doses (eg, 87 to 100 g/day), oat bran consumption resulted in a minimal effect on stool output (<1 g stool per gram fiber), likely because it outpaced the capacity of bacterial fermentation, but stool water content decreased (harder stools) in healthy subjects, which is inconsistent with a health benefit.[102-104] Taken together, the totality of clinical evidence shows that soluble fermentable fibers do not significantly increase stool output, and therefore do not provide a regularity benefit/laxative effect. Further, the lack of an effect on stool output by fermentable fibers debunks the concept that increasing the biomass provides a regularity benefit.

In contrast to readily fermented soluble fibers, gel-forming psyllium is not fermented in the human gut,[7,92,105] so it remains intact and present throughout the large bowel and retains its high water-holding capacity, providing bulky/soft stools that are easy to pass.[7,68,69,92] In a randomized, double-blind, 4-week (2-week baseline and 2-week treatment) clinical study that assessed the stool softening/laxative effects of psyllium (5.1 g twice a day) vs docusate (marketed as a stool softener, 100 mg twice a day) in 170 patients with chronic idiopathic constipation, the data showed that psyllium was superior to the stool softener for increasing stool water content (softer stools, $P<0.01$), stool output ($P<0.005$), and BM frequency ($P<0.05$).[69] A more recent randomized, placebo-controlled study investigated the effects of psyllium (10.5 g/day for 4 weeks) in 48 patients with chronic constipation.[106] The study showed that psyllium treatment significantly ($P<0.05$) reduced abdominal pain scores (−58%), reduced colonic transit time (−11 hours), increased BM frequency (threefold increase), and softened hard stools (+1 on the Bristol Stool Scale) vs placebo.[106]

It is important to note that observed increases in stool output for constipated patients will typically be lower than those observed for healthy subjects at the same fiber dose. For example, psyllium showed an increase in stool output of 4 to 5 g/g in healthy volunteers, but a smaller increase (1.4 to 3.7 g/g) in patients with chronic idiopathic constipation.[69,92,107,108] Many studies that assess the stool effects of isolated fibers are conducted with healthy subjects. It is important to note that an observed increase in stool output with healthy subjects is not necessarily predictive of a regularity benefit/laxative effect in constipation, particularly when the observed increase in stool output for healthy subjects is minimal (eg, ≤2 g/g) and is not associated with a significant increase in stool water content (stool-softening effect). To recommend an effective fiber therapy that treats/prevents constipation (maintains regularity), one must look for a fiber with multiple clinical studies showing reproducible evidence of a meaningful increase in both stool output (>2 g/g in healthy subjects and >1 g/g in constipated subjects) and stool water content (softer stools) at a reasonable dose (eg, ≤15 g/day) (eg, coarse wheat bran and psyllium).

Misconception #3d: If Fiber Provides a Significant Laxative Benefit, Too Much of that Fiber can Cause Diarrhea

In theory, this may be true for the mechanically irritating effects of insoluble fiber, particularly in patients with irritable bowel syndrome.[92,99,109-111] In contrast, if a gel-forming soluble fiber can resist fermentation (prerequisite #1) and retain its high water-holding capacity throughout the large bowel

Table 3. Clinically demonstrated health benefits associated with common fiber supplements

	No Water-Holding Capacity			Water-Holding Capacity			
		Soluble No Viscosity			Viscous/Gel-Forming		
Characteristic	Insoluble Wheat bran	Wheat dextrin	Inulin	Viscous Methylcellulose	Partially hydrolyzed guar gum	b-glucan	Psyllium
Example	All Bran[a]	Benefiber[b]	Fiber Choice[c]	MiraFiber Citrucel[d]	Generic	Quaker Oats[e]	Metamucil[f]
Source	Wheat	Chemically altered wheat starch	Chicory root	Chemically altered wood pulp	Guar beans	Oats, barley	Blonde psyllium seed husk
Natural?	Natural	Semisynthetic	Natural	Semisynthetic	Processed (↓ viscosity)	Natural	Natural
Degree of fermentation	Poorly fermented	Readily fermented	Readily fermented	Nonfermented	Readily fermented	Readily fermented	Nonfermented
Cholesterol lowering					±[g]	+[h]	+
Improved glycemic control					±[g]	+[h]	+
Constipation/stool softener	+[i]			±[j]			+
Diarrhea/stool normalizer							+

[a]Kellogg's.
[b]Novartis.
[c]Prestige Brands.
[d]GSK Group.
[e]Quaker Oats Company.
[f]Procter & Gamble.
[g]Raw guar gum a viscous/gel-forming fiber, but partially hydrolyzed guar gum is hydrolyzed to reduce viscosity (eliminate gelling) for improved palatability. A reduction in viscosity (loss of gel-formation) correlates with a reduction in/loss of efficacy.
[h]Typically marketed in fiber bars or cereals, requiring pressure and heat to make the final product, potentially reducing viscosity (gel-forming capacity). Efficacy depends on final viscosity (gel-forming).
[i]Efficacy is dependent on particle size/coarseness. Large/coarse particles show efficacy. Fine/smooth particles can be constipating.
[j]Methylcellulose has an over-the-counter indication for relief of constipation, but there are no well-controlled studies in constipated subjects to support this indication. The American College of Gastroenterology determined that methylcellulose had insufficient clinical data to recommend it for treatment of chronic constipation.[123]

(prerequisite #2), it can provide a dichotomous, stool normalizing effect to soften hard stool (increase BM frequency) in constipation,[68,92] and firm loose/liquid stool (decrease BM frequency) in diarrhea.[92] Psyllium has been shown to soften hard stool/reduce symptoms in patients with chronic constipation,[68,69,108] and improve stool form/reduce symptoms in chronic diarrhea,[112,113] lactulose-induced diarrhea,[114] Crohn's disease,[115] and phenolphthalein-induced diarrhea.[116] Clinical studies have also shown psyllium to be effective for normalizing stool form and reducing symptoms in irritable bowel syndrome.[99,117,118]

Misconception #3e: Fiber Exerts a Laxative/Regularity Benefit by Stimulating Large Bowel Motility

To understand how fiber exerts a laxative effect, it is important to understand the motor activity of large bowel, where ≈95% of motor events are segmental (mixing) pressure waves that facilitate the absorption of water and electrolytes, and the remaining ≈5% are propagating pressure waves (peristalsis) that propel contents toward the anus.[119-121] Propagating pressure waves occur over a wide range of amplitudes and propagating rates, from high amplitude (>100 mm Hg), slowly propagating (≤1 cm/second), infrequent (≤6/day) pressure waves that are lumen-occluding events (propel all contents), to low amplitude (10 mm Hg), rapidly propagating (≥10 cm/second), frequent (≥30/day) pressure waves that only propel gas.[7,119-121] Between these extremes are a range of medium amplitude/propagating rate pressure waves that propel lower viscosity substrates, like soft stool and liquids.[7,119]

How rapidly a substrate transits the large bowel is a function of viscosity. Gas, the lowest viscosity present in the large bowel, is easily propelled by all propagating pressure waves, but primarily by the small/frequent/fast waves that act like a squeegee to propel intestinal gas rapidly past other luminal contents (gurgling sound).[7,93,119] Gas can traverse the entire length of the large bowel in <30 minutes (≈14 flatulence episodes per day).[7,93,119] Liquid stool is propelled by all but the small/frequent/fast gas waves, resulting in rapid transit through the large bowel (≈1 to 2 hours) and the potential for frequent BMs (eg, diarrhea).[7,92,119] Formed stool is only propelled by high amplitude, infrequent, slow moving pressure waves, which is why solid contents may require days to transit the large bowel (≈1 BM per day).[7,92,119-121] If stool becomes very small and hard, it may no longer be effectively propelled by normal pressure waves, and may require intervention for evacuation (eg, enema).

An effective fiber for laxation does not alter large bowel motility,[122] but instead exerts a regularity benefit by altering the viscosity of stool.[7,68,69,92] With constipation, hard stools would only be propelled by a few of the highest amplitude contractions (or none at all, requiring intervention). A stool softening effect would decrease stool viscosity, making more of the existing motor events propulsive, increasing both colonic transit rate and the frequency of bulky/soft/easy-to-pass stools, thereby relieving symptoms of constipation.[7,92] With diarrhea, a stool normalizing/firming effect would increase the viscosity of stools, making fewer of the existing motor events propulsive, slowing transit and decreasing BM frequency.[7,92] An effective fiber can alter the viscosity of stool, thereby altering transit rate, but has no significant effect on motility in the large bowel.

CONCLUSIONS

There remains much misinformation in the literature about the physical effects of fiber in the gut. In the small bowel, fiber-related health benefits are dependent on the viscosity of soluble fibers. High viscosity fibers (eg, gel-forming b-glucan, psyllium, and raw guar gum) can have a significant beneficial effect on both cholesterol and glycemic control. In contrast, low viscosity/nonviscous fibers (eg, low-molecular-weight b-glucan, methylcellulose, inulin, wheat dextrin) and insoluble fiber (eg, wheat bran and cellulose) have no significant effect on cholesterol concentrations or glycemic control, and can be used as a placebo. In the large bowel, there are two mechanisms that drive a regularity/laxative benefit: insoluble fiber mechanically irritates the gut mucosa to stimulate mucous/water secretion, and soluble gel-forming fiber that retains a high-water holding capacity that resists dehydration. To exert a regularity benefit or laxative effect, a fiber must resist fermentation to remain intact and present throughout the large bowel (be present in stool), and significantly increase stool water content. The increase in stool water content provides bulky/soft/easy-to-pass stools. The plastic effect of insoluble fiber (eg, wheat bran) is dependent on particle size/coarseness: large/coarse particles have a significant laxative effect; small/smooth particles can have a constipating effect (add only to the dry mass of stool, decreasing percent water content/hardening stools). The high water-holding capacity of a nonfermented gel-forming fiber (eg, psyllium) can provide a dichotomous stool normalizing effect; that is, soften hard stool in constipation and firm-up loose/liquid stools in diarrhea, and normalizing stool form in patients with irritable bowel syndrome. In contrast, the lack of water-holding capacity for fine insoluble fiber (eg, fine wheat bran) and fermentable soluble fiber (eg, wheat dextrin) can lead to a constipating effect, resulting in a decrease in stool water content/harder stools. It is therefore essential to recognize which fibers possess specific health-promoting properties, and which fiber supplements have consistent, rigorous evidence of clinically meaningful health benefits at the doses commonly available in the market place (Table 3).

References

1. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes: Energy, Carbohydrates, Fiber, Fat, Fatty Acids Cholesterol, Protein and Amino Acids*. Washington, DC: The National Academies Press; 2002.
2. Cummings JH, Bingham SA, Heaton KW, Eastwood MA. Fecal weight, colon cancer risk and dietary intake of nonstarch polysaccharides (dietary fiber). *Gastroenterology*. 1992;103(6):1783-1789.
3. Franco-Robles E, López M. Implication of fructans in health: Immunomodulatory and antioxidant mechanisms. *Scientific World J*. 2015;2015:289267.
4. Seal CJ, Nugent AP, Tee ES, Thielecke F. Whole-grain dietary recommendations: The need for a unified global approach. *Br J Nutr*. 2016;115(11):2031-2038.
5. Dehghan P, Farhangi MA, Tavakoli F, Aliasgarzadeh A, Akbari A. Impact of prebiotic supplementation on T-cell subsets and their related cytokines, anthropometric features and blood pressure in patients with type 2 diabetes mellitus: A randomized placebo-controlled trial. *Complement Ther Med*. 2016;24:96-102.
6. Law M, Wald N, Rudnicka A. Quantifying effect of statins on low density lipoprotein cholesterol, ischaemic heart disease, and

stroke: Systematic review and meta-analysis. *BMJ*. 2003;326(7404):1423-1429.

7. McRorie J, Fahey G. Chapter 8: Fiber supplements and clinically meaningful health benefits: Identifying the physiochemical characteristics of fiber that drive specific physiologic effects. In: Taylor C, ed. *The CRC Handbook on Dietary Supplements in Health Promotion*. Florence, KY: CRC Press; 2015.
8. Pereira D, Gibson G. Effects of consumption of probiotics and prebiotics on serum lipid levels in humans. *Crit Rev Biochem Mol Biol*. 2002;37(4):259-281.
9. Jackson K, Taylor G, Clohessy A, Williams C. The effect of the daily intake of inulin on fasting lipid, insulin and glucose concentrations in middle-aged men and women. *Br J Nutr*. 1999;82(1):23-30.
10. Pedersen A, Sandstrom B, Van Amelsvoort J. The effect of ingestion of inulin on blood lipids and gastrointestinal symptoms in healthy females. *Br J Nutr*. 1997;78(2):215-222.
11. Luo J, Rizkalla S, Alamowitch C, et al. Chronic consumption of short-chain fructooligosaccharides by healthy subjects decreased basal hepatic glucose production but had no effect on insulin-stimulated glucose. *Am J Clin Nutr*. 1996;63(6):939-945.
12. Causey J, Feirtag J, Gahaher D, Tuqland B, Slavin J. Effects of dietary inulin on serum lipids, blood glucose and the gastrointestinal environment in hypercholesterolemic men. *Nutr Res*. 2000;20(2):191-201.
13. Giaccoa R, Clementea G, Luongoa D, et al. Effects of short-chain fructo-oligosaccharides on glucose and lipid metabolism in mild hypercholesterolaemic individuals. *Clin Nutr*. 2004;23(3):331-340.
14. Alles M, de Roos N, Bakx J, van de Lisdonk E, Zock P, Hautvast J. Consumption of fructooligosaccharides does not favorably affect blood glucose and serum lipid concentrations in patients with type 2 diabetes. *Am J Clin Nutr*. 1999;69:64-69.
15. Letexier D, Diraison F, Beylot M. Addition of inulin to a moderately high-carbohydrate diet reduces hepatic lipogenesis and plasma triacylglycerol concentrations in humans. *Am J Clin Nutr*. 2003;77(3):559-564.
16. Luo J, Van Yperselle M, Rizkalla S, Rossi F, Bornet F, Salma G. Chronic consumption of short-chain fructooligosaccharides does not affect basal hepatic glucose production or insulin resistance in type 2 diabetics. *J Nutr*. 2000;130:1572-1577.
17. Forcherona F, Beylot M. Long-term administration of inulin-type fructans has no significant lipid-lowering effect in normolipidemic humans. *Metabolism*. 2007;56(8):1093-1098.
18. de Luis A, de la Fuente B, Izaola O, Aller R, Gutiérrez S, Morillo M. Double blind randomized clinical trial controlled by placebo with a FOS enriched cookie on satiety and cardiovascular risk factors in obese patients. *Nutr Hosp*. 2013;28(1):78-85.
19. Dewulf E, Cani P, Claus S, et al. Insight into the prebiotic concept: Lessons from an exploratory, double blind intervention study with inulin-type fructans in obese women. *Gut*. 2013;62(8):1112-1121.
20. Parnell J, Reimer R. Weight loss during oligofructose supplementation is associated with decreased ghrelin and increased peptide YY in overweight and obese adults. *J Clin Nutr*. 2009;89(6):1751-1759.
21. Tovar A, Caamaño M, Garcia-Padilla S, García O, Duarte M, Rosado J. The inclusion of a partial meal replacement with or without inulin to a calorie restricted diet contributes to reach recommended intakes of micronutrients and decrease plasma triglycerides: A randomized clinical trial in obese Mexican women. *Nutr J*. 2012;11:44-53.
22. Vulevic J, Juric A, Tzortzis G, Gibson G. A mixture of trans-galactooligosaccharides reduces markers of metabolic syndrome and modulates the fecal microbiota and immune function of overweight adults. *J Nutr*. 2013;143(3):324-331.
23. Davidson M, Maki K. Effects of dietary inulin on serum lipids. *J Nutr*. 1999;129(7 suppl):1474S-1477S.
24. Russo F, Chimienti G, Riezzo G, et al. Inulin-enriched pasta affects lipid profile and Lp(a) concentrations in Italian young healthy male volunteers. *Eur J Nutr*. 2008;47(8):453-459.
25. Daubioul C, Horsmans Y, Lambert P, Danse E, Delzenne N. Effects of oligofructose on glucose and lipid metabolism in patients with nonalcoholic steatohepatitis: Results of a pilot study. *Eur J Clin Nutr*. 2005;59(5):723-726.
26. Wolever T, Tosh S, Gibbs A, Brand-Miller J. Physicochemical properties of oat β-glucan influence its ability to reduce serum LDL cholesterol in humans: A randomized clinical trial. *Am J Clin Nutr*. 2010;92(4):723-732.
27. Kerkhoffs D, Hornstra G, Mensick R. Cholesterol-lowering effect of β-glucan from oat bran in mildly hypercholesterolemic subjects may decrease when β-glucan is incorporated into bread and cookies. *Am J Clin Nutr*. 2003;78(2):221-227.
28. Haskell W, Spiller G, Jensen C, Ellis B, Gates J. Role of water-soluble dietary fiber in the management of elevated plasma cholesterol in healthy subjects. *Am J Cardiol*. 1992;69(5):433-439.
29. Kim J, Cha YJ, Lee KH, Park E. Effect of onion peel extract supplementation on the lipid profile and antioxidative status of healthy young women: A randomized, placebo-controlled, double-blind, crossover trial. *Nutr Res Pract*. 2013;7(5):373-379.
30. Vuksan V, Jenkins A, Rogovik A, Fairgrieve C, Jovanovski E, Leiter L. Viscosity rather than quantity of dietary fibre predicts cholesterol-lowering effect in healthy individuals. *Br J Nutr*. 2011;106:1349-1352.
31. McRorie J. Evidence-based approach to fiber supplements and clinically meaningful health benefits, part 1: What to look for and how to recommend an effective fiber therapy. *Nutr Today*. 2015;50(2):82-89.
32. Ribas S, Cunha D, Sichieri R, da Silva L. Effects of psyllium on LDL-cholesterol concentrations in Brazilian children and adolescents: A randomised, placebo-controlled, parallel clinical trial. *Br J Nutr*. 2015;113(1):134-141.
33. Anderson J, Allgood L, Lawrence A, et al. Cholesterol-lowering effects of psyllium intake adjunctive to diet therapy in men and women with hypercholesterolemia: meta-analysis of 8 controlled trials. *Am J Clin Nutr*. 2000;71(2):1472-1479.
34. Anderson J, Floore T, Geil P, Spencer D, Balm T. Hypocholesterolemic effects of different bulk-forming hydrophilic fibers as a adjuncts to dietary therapy in mild to moderate hypercholesterolemia. *Arch Intern Med*. 1991;151(8):1597-1602.
35. Olson B, Anderson S, Becker M, et al. Psyllium-enriched cereals lower blood total cholesterol and LDL cholesterol, but not HDL cholesterol, in hypercholesterolemic adults: Results of a meta-analysis. *J Nutr*. 1997;127(10):1973-1980.
36. Anderson J, Zettwoch N, Feldman T, Tietyen-Clark J, Oeltgen P, Bishop C. Cholesterol-lowering effects of psyllium hydrophilic mucilloid for hypercholetserolemic men. *Arch Intern Med*. 1998;148(2):292-296.
37. Gupta R, Agrawal C, Singh G, Ghatak A. Lipid-lowering efficacy of psyllium hydrophilic mucilloid in non-insulin dependent diabetes mellitus with hyperlipidemia. *Indian J Med Res*. 1994;100:237-241.
38. Cicero A, Derosa G, Bove M, Imola F, Borghi C, Gaddi A. Psyllium improves dyslipidaemia, hyperglycaemia and hypertension, while guar gum reduces body weight more rapidly in patients affected by metabolic syndrome following an AHA Step 2 diet. *Mediterr J Nutr Metab*. 2010;3:47-54.
39. Rodriguez-Moran M, Guerrero-Romero F, Laczano-Burciaga L. Lipid- and glucose-lowering efficacy of plantago psyllium in type II diabetes. *J Diabetes Complicat*. 1998;12(5):273-278.
40. Anderson J, Allgood L, Turner C, Oelgten P, Daggy B. Effects of psyllium on glucose and serum lipid responses in men with type 2 diabetes and hypercholesterolemia. *Am J Clin Nutr*. 1999;70(4):466-473.
41. Jenkins D, Wolever T, Vidgen E, et al. Effect of psyllium in hypercholesterolemia at two monounsaturated fatty acid intakes. *Am J Clin Nutr*. 1997;65(5):1524-1533.
42. Everson G, Daggy B, McKinley C, Story J. Effects of psyllium hydrophilic mucilloid on LDL-cholesterol and bile acid synthesis in hypercholesterolemic men. *J Lipid Res*. 1992;33(8):1183-1192.
43. Levin E, Miller V, Muesing R, Stoy D, Balm T, LaRosa J. Comparison of psyllium hydrophilic mucilloid and cellulose as adjuncts to a prudent diet in the treatment of mild to moderate hypercholesterolemia. *Arch Intern Med*. 1990;150(9):1822-1827.
44. Stoy D, LaRosa J, Brewer B, Mackey M, Meusing R. Cholesterol-lowering effects of ready-to-eat cereal containing psyllium. *J Am Diet Assoc*. 1993;93(8):910-912.
45. Sprecher D, Harris B, Goldberg A. Efficacy of psyllium in reducing serum cholesterol levels in hypercholesterolemic patients on high- and low-fat diets. *Ann Intern Med*. 1993;119(pt 1):545-554.

46. Summerbell C, Manley P, Barnes D, Leeds A. The effects of psyllium on blood lipids in hypercholesterolaemic subjects. *J Hum Nutr Diet*. 1994;7:147-151.
47. Bell L, Hectorne K, Reynolds H, Balm T, Hunninghake D. Cholesterol-lowering effects of psyllium hydrophilic mucilloid: Adjunct therapy to a prudent diet for patients with mild to moderate hypercholesterolemia. *JAMA*. 1989;261(23):3419-3423.
48. Bell L, Hectorn K, Reynolds H, Hunninghake D. Cholesterol-lowering effects of soluble-fiber cereals as part of a prudent diet for patients with mild to moderate hypercholesterolemia. *Am J Clin Nutr*. 1990;52(6):1020-1026.
49. Weingand K, Le N, Kuzmak B, et al. Effects of psyllium on cholesterol and low-density lipoprotein. *Endocrinol Metab*. 1997;4:141-150.
50. de Bock M, Derraik J, Brennan C, et al. Psyllium supplementation in adolescents improves fat distribution and lipid profile: A randomized, participant-blinded, placebo-controlled, crossover trial. *PLoS ONE*. 2012;7(7):e41735.
51. Romero A, Romero J, Galaviz S, Fernandez M. Cookies enriched with psyllium or oat bran lower plasma LDL cholesterol in normal and hypercholesterolemic men from Northern Mexico. *J Am Coll Nutr*. 1998;17(6):601-608.
52. Shrestha S, Freake H, McGrane M, Volek J, Fernandez M. A combination of psyllium and plant sterols alters lipoprotein metabolism in hypercholesterolemic subjects by modifying the intravascular processing of lipoproteins and increasing LDL uptake. *J Nutr*. 2007;137(5):1165-1170.
53. Shrestha S, Volek J, Udani J, et al. A combination therapy including psyllium and plant sterols lowers LDL cholesterol by modifying lipoprotein metabolism in hypercholesterolemic individuals. *J Nutr*. 2006;136(10):2492-2497.
54. Neal G, Balm T. Synergistic effects of psyllium in the dietary treatment of hypercholesterolemia. *South Med J*. 1990;83(10):1131-1137.
55. Moreyra A, Wilson A, Koraym A. Effect of combining psyllium fiber with simvastatin in lowering cholesterol. *Arch Int Med*. 2005;165(10):1161-1166.
56. Maciejko J, Brazg R, Shah A, Patil S, Rubenfire M. Psyllium for the reduction of cholestyramine-associated gastrointestinal symptoms in the treatment of primary hypercholesterolemia. *Arch Fam Med*. 1994;3(11):955-960.
57. Spence J, Huff M, Heidenheim P, Viswanatha A, Munoz C, Lindsay R. Combination therapy with colestipol and psyllium mucilloid in patients with hyperlipidemia. *Ann Intern Med*. 1995;123(7):493-499.
58. Agrawal A, Tandon M, Sharma P. Effect of combining viscous fibre with lovastatin on serum lipids in normal human subjects. *Int J Clin Pract*. 2007;61(11):1812-1818.
59. Jayaram S, Prasad H, Sovani V, Langade D, Mane P. Randomized study to compare the efficacy and safety of isapgol plus atorvastatin versus atorvastatin alone in subjects with hypercholesterolaemia. *J Indian Med Assoc*. 2007;105(3):142-145.
60. Code of Federal Regulations, Title 21. http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=101.81 Accessed March 6, 2015.
61. Jenkins D, Wolever T, Leeds A, Gassull M, Haisman P, Dilawari J. Dietary fibres, fibre analogues, and glucose tolerance: Importance of viscosity. *BMJ*. 1978;1:1392-1394.
62. Ziai S, Larijani B, Akhoondzadeh S, Fakhzadeh H, Dastpak A, Bandarian F. Psyllium decreased serum glucose and glycosylated hemoglobin significantly in diabetic outpatients. *J Ethnopharmacol*. 2005;102:202-207.
63. Feinglos M, Gibb R, Ramsey D, Surwit R, McRorie J. Psyllium improves glycemic control in patients with type-2 diabetes mellitus. *Bio Carb Dietary Fibre*. 2013;1:156-161.
64. Dall'Alba V, Silva FM, Antonio JP, et al. Improvement of the metabolic syndrome profile by soluble fibre—guar gum—in patients with type 2 diabetes: A randomised clinical trial. *Br J Nutr*. 2013;110(9):1601-1610.
65. Maljaars P, Peters H, Mela D, Masclee A. Ileal brake: A sensible food target for appetite control. A review. *Physiol Behav*. 2008;95:271-281.
66. Kawasaki N, Suzuki Y, Urashima M, et al. Effect of gelatinization on gastric emptying and absorption. *Hepatogastroenterol*. 2008;55(86-87):1843-1845.
67. Gibb R, McRorie J, Russell D, Hasselblad V, D'Alessio D. Psyllium fiber improves glycemic control proportional to loss of glycemic control: A meta-analysis of data in euglycemic subjects, patients at risk of type 2 diabetes mellitus, and patients being treated for type 2 diabetes mellitus. *Am J Clin Nutr*. 2015;102(6):1604-1614.
68. McRorie J, Pepple S, Rudolph C. Effects of fiber laxatives and calcium docusate on regional water content and viscosity of digesta in the large intestine of the pig. *Dig Dis Sci*. 1998;43(4):738-745.
69. McRorie J, Daggy B, Morel J, Diersing P, Miner P, Robinson M. Psyllium is superior to docusate sodium for treatment of chronic constipation. *Aliment Pharm Ther*. 1998;12:491-497.
70. McRorie J, Zorich N, Riccardi K, Bishop L, Filloon T, Wason S, Giannella R. Effects of Olestra and sorbitol consumption on objective measures of diarrhea: Impact of stool viscosity on common gastrointestinal symptoms. *Reg Tox Pharm*. 2000;31(1):59-67.
71. Slavin J, Feirtag J. Chicory inulin does not increase stool weight or speed up intestinal transit time in healthy male subjects. *Food Funct*. 2011;2:72-77.
72. Costabile A, Fava F, Roytio H, et al. Impact of polydextrose on the faecal microbiota: A double-blind, crossover, placebo-controlled feeding study in healthy human subjects. *Br J Nutr*. 2012;108:471-481.
73. Costabile A, Kolida S, Klinder A, et al. A double-blind, placebo-controlled, cross-over study to establish the bifidogenic effect of a very-long-chain inulin extracted from globe artichoke (*Cynara scolymus*) in healthy human subjects. *Br J Nutr*. 2010;104:1007-1017.
74. van Dokkum W, Wezendonk B, Srikumar T, van den Heuvel E. Effect of nondigestible oligosaccharides on large-bowel functions, blood lipid concentrations and glucose absorption in young healthy male subjects. *Eur J Clin Nutr*. 1999;53(1):1-7.
75. Ramnani P, Gaudier E, Bingham M, van Bruggen P, Tuohy K, Gibson G. Prebiotic effect of fruit and vegetable shots containing Jerusalem artichoke inulin: A human intervention study. *Br J Nutr*. 2010;104(2):233-240.
76. Kleessen B, Schwarz S, Boehm A, et al. Jerusalem artichoke and chicory inulin in bakery products affect faecal microbiota of healthy volunteers. *Br J Nutr*. 2007;98(3):540-549.
77. Waitzberg L, Pereira A, Logullo L, et al. Microbiota benefits after inulin and partially hydrolized guar gum supplementation: A randomized clinical trial in constipated women. *Nutr Hosp*. 2012;27(1):123-129.
78. Marteau P, Jacobs H, Cazabiel M, Signoret C, Prevel J, Housez B. Effects of chicory inulin in constipated elderly people: A double-blind controlled trial. *Int J Food Sci Nutr*. 2011;62(2):164-170.
79. Dahl W, Whiting S, Isaac T, Weeks S, Arnold C. Effects of thickened beverages fortified with inulin on beverage acceptance, gastrointestinal function, and bone resorption in institutionalized adults. *Nutr*. 2005;21(3):308-311.
80. Den Hand E, Geypens B, Ghoos Y. Effect of high performance chicory inulin on constipation. *Nutr Res*. 2000;20(5):731-736.
81. Boler B, Serao M, Bauer L, et al. Digestive physiological outcomes related to polydextrose and soluble corn fibre consumption by healthy adult men. *Br J Nutr*. 2011;106:1864-1871.
82. Stewart M, Nikhanj S, Timm D, Thomas W, Slavin J. Evaluation of the effect of four fibers on laxation, gastrointestinal tolerance and serum markers in healthy humans. *Ann Nutr Metab*. 2010;56:91-98.
83. Timm D, Thomas W, Boileau T, Williamson-Hughes P, Slavin J. Polydextrose and soluble corn fiber increase five-day fecal weight in healthy men and women. *J Nutr*. 2013;143:473-478.
84. van den Heuvel E, Wils D, Pasman W, Saniez M, Kardinaal A. Dietary supplementation of different doses of NUTRIOSE-FB, a fermentable dextrin, alters the activity of faecal enzymes in healthy men. *Eur J Nutr*. 2005;44:445-451.
85. van den Heuvel E, Wils D, Pasman W, Bakker M, Saniez M, Kardinaal A. Short-term digestive tolerance of different doses of NUTRIOSE FB, a food dextrin, in adult men. *Eur J Clin Nutr*. 2004;58(7):1046-1055.
86. Jie Z, Bang-Yao L, Ming-Jie X, Hai-Wei L, Zu-Kang Z, Ting-Song W, Craig S. Studies on the effects of polydextrose intake on physiologic functions in Chinese people. *Am J Clin Nutr*. 2000;72:1503-1509.
87. Hengst C, Ptok S, Roessler A, Fechner A, Jahreis G. Effects of polydextrose supplementation on different fecal parameters in healthy volunteers. *Int J Food Sci Nutr*. 2009;60(suppl 5):96-105.

88. Hamilton J, Wagner J, Burdick B, Bass P. Clinical evaluation of methylcellulose as a bulk laxative. *Dig Dis Sci*. 1988;33(8):993-998.
89. Slavin J, Savarino V, Paredes-Diaz A, Fotopoulos G. A review of the role of soluble fiber in health with specific reference to wheat dextrin. *J Int Med Res*. 2009;37(1):1-17.
90. Taghipoor M, Barles G, Georgelin C, Licois J, Lescoat P. Digestion modeling in the small intestine: Impact of dietary fiber. *Math Biosci*. 2014;258:101-112.
91. Mudgil D, Barak S. Composition, properties and health benefits of indigestible carbohydrate polymers as dietary fiber: A review. *Int J Biol Macromol*. 2013;61:1-6.
92. McRorie J. Evidence-based approach to fiber supplements and clinically meaningful health benefits, part 2: What to look for and how to recommend an effective fiber therapy. *Nutr Today*. 2015;50(2):90-97.
93. Brodribb A, Groves C. Effect of bran particle size on stool weight. *Gut*. 1978;19(1):60-63.
94. Tomlin J, Read N. Laxative properties of indigestible plastic particles. *BMJ*. 1988;297:1175-1176.
95. Lewis S, Heaton K. The intestinal effects of bran-like plastic particles: Is the concept of 'roughage' valid after all? *Eur J Gastroenterol Hepatol*. 1997;9(6):553-557.
96. Lewis S, Heaton K. Roughage revisited: The effect on intestinal function of inert plastic particles of different sizes and shapes. *Dig Dis Sci*. 1999;44:744-748.
97. Wrick K, Robertson J, von Soest P, et al. The influence of dietary fiber source on human intestinal transit and stool output. *J Nutr*. 1983;113:1464-1479.
98. Francis C, Whorwell P. Bran and irritable bowel syndrome: Time for reappraisal. *Lancet*. 1994;344:39-40.
99. Eswaran S, Muir J, Chey W. Fiber and functional gastrointestinal disorders. *Am J Gastroenterol*. 2013;108:718-727.
100. Wolever T, Robb P. Effect of guar, pectin, psyllium, soy polysaccharide and cellulose on breath hydrogen and methane in healthy subjects. *Am J Gastroenterol*. 1992;87:305-310.
101. Lampe J, Effertz M, Larson J, Slavin J. Gastrointestinal effects of modified guar gum and soy polysaccharide as part of an enteral formula diet. *J Parenter Enteral Nutr*. 1992;16(6):538-544.
102. Chen H, Haack V, Janecky C, Vollendorf N, Marlett J. Mechanisms by which wheat bran and oat bran increase stool weight in humans. *Am J Clin Nutr*. 1998;68:711-719.
103. Spencer H, Norris C, Derler J, Osis D. Effect of oat bran muffins on calcium absorption and calcium, phosphorus, magnesium and zinc balance in men. *J Nutr*. 1991;121:1976-1983.
104. Kirby R, Anderson J, Sieling B, et al. Oat-bran intake selectively lowers serum low density lipoprotein cholesterol concentrations of hypercholesterolemic men. *Am J Clin Nutr*. 1981;34:824-829.
105. McRorie J. Clinical data support that psyllium is not fermented in the gut [letter to the Editor]. *Am J Gastroenterol*. 2013;108(9):1541.
106. Vega A, Perelló A, Martos L, et al. Breath methane in functional constipation: Response to treatment with ispaghula husk. *Neurogastroenterol Motil*. 2015;27:945-953.
107. Chaplin M, Chaudhury S, Dettmar P, Sykes J, Shaw A, Davies G. Effect of ispaghula husk on the faecal output of bile acids in healthy volunteers. *J Steroid Biochem Mol Biol*. 2000;72(5):283-292.
108. Ashraf W, Park F, Lof J, Quigley E. Effects of psyllium therapy on stool characteristics, colon transit and anorectal function in chronic idiopathic constipation. *Aliment Pharmacol Ther*. 1995;9(6):639-647.
109. Brandt L, Prather C, Quigley E, Schiller L, Schoenfeld P, Talley N. Systematic review on the management of chronic constipation in North America. *Am J Gastroenterol*. 2005;100(suppl):S5-S22.
110. Ford A, Moayyedi P, Lacy B, et al. American College of Gastroenterology monograph on the management of irritable bowel syndrome and chronic idiopathic constipation. *Am J Gastroenterol*. 2014;109(suppl):S2-S26.
111. Bijkerk C, de Wit N, Muris J, Whorwell P, Knottnerus J, Hoes A. Soluble or insoluble fibre in irritable bowel syndrome in primary care? Randomised placebo controlled trial. *Br Med J*. 2009;27;339:b3154.
112. Qvitzau S, Matzen P, Madsen P. Treatment of chronic diarrhoea: Loperamide versus ispaghula husk and calcium. *Scand J Gastroenterol*. 1988;23:1237-1240.
113. Wenzl H, Fine K, Schiller L, Fordtran J. Determinants of decreased fecal consistency in patients with diarrhea. *Gastroenterol*. 1995;108(6):1729-1738.
114. Washington N, Harris M, Mussellwhite A, Spiller R. Moderation of lactulose-induced diarrhea by psyllium: Effects on motility and fermentation. *Am J Clin Nutr*. 1998;67:317-321.
115. Fujimori S, Tatsuguchi A, Gudis K, et al. High dose probiotic and prebiotic cotherapy for remission induction of active Crohn's disease. *J Gastroenterol Hepatol*. 2007;22(8):1199-1204.
116. Eherer A, Santa Ana C, Fordtran J. Effect of psyllium, calcium polycarbophil, and wheat bran on secretory diarrhea induced by phenolphthalein. *Gastroenterology*. 1993;104:1007-1012.
117. Prior A, Whorwell P. Double blind study of ispaghula in irritable bowel syndrome. *Gut*. 1987;28(11):1510-1513.
118. Kumar A, Kumar N, Vij J, Sarin S, Anand B. Optimum dosage of ispaghula husk in patients with irritable bowel syndrome: Correlation of symptom relief with whole gut transit time and stool weight. *Gut*. 1987;28(2):150-155.
119. McRorie J, Greenwood-Van Meerveld B, Rudolph C. Characterization of propagating contractions in the proximal colon of ambulatory mini pigs. *Dig Dis Sci*. 1998;43(5):957-963.
120. Bassotti G, Crowell M, Whitehead W. Contractile activity of the human colon: Lessons from 24 hour studies. *Gut*. 1993;34(1):129-133.
121. Bassotti G, Iantorno G, Fiorella S, Bustos-Fernandez L, Bilder C. Colonic motility in man: Features in normal subjects and in patients with chronic idiopathic constipation. *Am J Gastroenterol*. 1999;94(7):1760-1770.
122. Greenwood-van Meerveld B, Neeley D, Tyler K, Peters L, McRorie J. Comparison of effects on colonic motility and stool characteristics associated with feeding Olestra and wheat bran to ambulatory mini-pigs. *Dig Dis Sci*. 1999;44(7):1282-1287.
123. Brandt LJ, Prather CM, Quigley EM, Schiller LR, Schoenfeld P, Talley NJ. Systematic review on the management of chronic constipation in North America. *Am J Gastroenterol*. 2005;100(suppl 1):S5-S22.

AUTHOR INFORMATION

J. W. McRorie, Jr, is a clinical scientist, Global Clinical Sciences, Procter & Gamble, Mason, OH. N. M. McKeown is a scientist, Jean Mayer US Department of Agriculture Human Nutrition Research Center on Aging, Tufts University, Boston, MA.

Address correspondence to: Johnson W. McRorie, Jr, PhD, Global Clinical Sciences, Procter & Gamble, Mason Business Center, 8700 Mason-Montgomery Rd, Mason, OH 45040. E-mail: mcrorie.jw@pg.com

STATEMENT OF POTENTIAL CONFLICT OF INTEREST

Johnson W. McRorie, Jr, PhD, is a full-time employee of the Procter & Gamble Company, which markets a fiber product. Nicola M. McKeown, PhD, received grants from the International Life Sciences Institute North America, the General Mills Bell Institute of Health and Nutrition, and an unrestricted gift from Procter and Gamble. She is an unpaid science advisor for the Whole Grains Council.

FUNDING/SUPPORT

Nicola M. McKeown, PhD, is supported in part by the US Department of Agriculture, Agricultural Research Service (grant no. 58-1950-4-003); ILSI North America; the General Mills Bell Institute of Health and Nutrition; and the American Heart Association.